

|  |   |   |
|--|---|---|
| FORM PTO-1390 (Modified)<br>(REV 11-2000)  | U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE | ATTORNEY'S DOCKET NUMBER<br><b>20568-68741</b>                |
| TRANSMITTAL LETTER TO THE UNITED STATES<br>DESIGNATED/ELECTED OFFICE (DO/EO/US)<br>CONCERNING A FILING UNDER 35 U.S.C. 371 |   | U.S. APPLICATION NO (IF KNOWN, SEE 37 CFR<br><b>09/913578</b> |

|  |  |   |
|--|--|---|
| INTERNATIONAL APPLICATION NO.<br><b>PCT/US00/02470</b> | INTERNATIONAL FILING DATE<br><b>31 JANUARY 2000 (31.01.00)</b> | PRIORITY DATE CLAIMED<br><b>15 FEBRUARY 1999 (15.02.99)</b> |
|--|--|---|

TITLE OF INVENTION  
**FLEXIBLE AND SCALABLE ARCHITECTURE FOR DWDM NETWORKS IN FIBER RINGS**

APPLICANT(S) FOR DO/EO/US  
**OREN, Yair, et al**

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1.  This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2.  This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3.  This is an express request to begin national examination procedures (35 U.S.C. 371(f)). The submission must include items (5), (6), (9) and (24) indicated below.
4.  The US has been elected by the expiration of 19 months from the priority date (Article 31).
5.  A copy of the International Application as filed (35 U.S.C. 371 (c) (2))
  - a.  is attached hereto (required only if not communicated by the International Bureau).
  - b.  has been communicated by the International Bureau.
  - c.  is not required, as the application was filed in the United States Receiving Office (RO/US).
6.  An English language translation of the International Application as filed (35 U.S.C. 371(c)(2)).
  - a.  is attached hereto.
  - b.  has been previously submitted under 35 U.S.C. 154(d)(4).
7.  Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371 (c)(3))
  - a.  are attached hereto (required only if not communicated by the International Bureau).
  - b.  have been communicated by the International Bureau.
  - c.  have not been made; however, the time limit for making such amendments has NOT expired.
  - d.  have not been made and will not be made.
8.  An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9.  An oath or declaration of the inventor(s) (35 U.S.C. 371 (c)(4)). (UNEXECUTED)
10.  An English language translation of the annexes of the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371 (c)(5)).
11.  A copy of the International Preliminary Examination Report (PCT/IPEA/409).
12.  A copy of the International Search Report (PCT/ISA/210).

**Items 13 to 20 below concern document(s) or information included:**

13.  An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
14.  An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
15.  A **FIRST** preliminary amendment.
16.  A **SECOND** or **SUBSEQUENT** preliminary amendment.
17.  A substitute specification.
18.  A change of power of attorney and/or address letter.
19.  A computer-readable form of the sequence listing in accordance with PCT Rule 13ter.2 and 35 U.S.C. 1.821 - 1.825.
20.  A second copy of the published international application under 35 U.S.C. 154(d)(4).
21.  A second copy of the English language translation of the international application under 35 U.S.C. 154(d)(4).
22.  Certificate of Mailing by Express Mail
23.  Other items or information:

**LETTER REQUESTING THAT ENTRY START ON THE BASIS OF THE INTERNATIONAL APPLICATION AS ORIGINALLY FILED.**

|  |   |   |
|--|---|---|
| U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR<br><b>09/913578</b> ) | INTERNATIONAL APPLICATION NO.<br>PCT/US00/02470 | ATTORNEY'S DOCKET NUMBER<br>20568-68741 |
|--|---|---|

|  |                     |                     |                  |                                  |           |
|--|---------------------|---------------------|------------------|----------------------------------|-----------|
| 24. The following fees are submitted:.   |                     |                     |                  | <b>CALCULATIONS PTO USE ONLY</b> |           |
| <b>BASIC NATIONAL FEE ( 37 CFR 1.492 (a) (1) - (5) ) :</b>   |                     |                     |                  |                                  |           |
| <input type="checkbox"/> Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO . . . . . |                     |                     | <b>\$1000.00</b> |                                  |           |
| <input type="checkbox"/> International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO . . . . .   |                     |                     | <b>\$860.00</b>  |                                  |           |
| <input type="checkbox"/> International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO . . . . .  |                     |                     | <b>\$710.00</b>  |                                  |           |
| <input checked="" type="checkbox"/> International preliminary examination fee (37 CFR 1.482) paid to USPTO but all claims did not satisfy provisions of PCT Article 33(1)-(4) . . . . .  |                     |                     | <b>\$690.00</b>  |                                  |           |
| <input type="checkbox"/> International preliminary examination fee (37 CFR 1.482) paid to USPTO and all claims satisfied provisions of PCT Article 33(1)-(4) . . . . .   |                     |                     | <b>\$100.00</b>  |                                  |           |
| <b>ENTER APPROPRIATE BASIC FEE AMOUNT =</b>  |                     |                     |                  | <b>\$690.00</b>                  |           |
| Surcharge of <b>\$130.00</b> for furnishing the oath or declaration later than months from the earliest claimed priority date (37 CFR 1.492 (e)). <input type="checkbox"/> 20 <input type="checkbox"/> 30                          |                     |                     |                  | <b>\$0.00</b>                    |           |
| <b>CLAIMS</b>  | <b>NUMBER FILED</b> | <b>NUMBER EXTRA</b> | <b>RATE</b>      |                                  |           |
| Total claims   | 20 - 20 =           | 0                   | x \$18.00        | <b>\$0.00</b>                    |           |
| Independent claims   | 3 - 3 =             | 0                   | x \$80.00        | <b>\$0.00</b>                    |           |
| Multiple Dependent Claims (check if applicable). <input type="checkbox"/>  |                     |                     |                  | <b>\$0.00</b>                    |           |
| <b>TOTAL OF ABOVE CALCULATIONS =</b>   |                     |                     |                  | <b>\$690.00</b>                  |           |
| <input type="checkbox"/> Applicant claims small entity status (Sec 37 CFR 1.27). The fees indicated above are reduced by 1/2.  |                     |                     |                  | <b>\$0.00</b>                    |           |
| <b>SUBTOTAL =</b>  |                     |                     |                  | <b>\$690.00</b>                  |           |
| Processing fee of <b>\$130.00</b> for furnishing the English translation later than months from the earliest claimed priority date (37 CFR 1.492 (f)). <input type="checkbox"/> 20 <input type="checkbox"/> 30                     |                     |                     |                  | <b>\$0.00</b>                    |           |
| <b>TOTAL NATIONAL FEE =</b>  |                     |                     |                  | <b>\$690.00</b>                  |           |
| Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31) (check if applicable). <input type="checkbox"/>                                   |                     |                     |                  | <b>\$0.00</b>                    |           |
| <b>TOTAL FEES ENCLOSED =</b>   |                     |                     |                  | <b>\$690.00</b>                  |           |
|  |                     |                     |                  | <b>Amount to be:</b>             | <b>\$</b> |
|  |                     |                     |                  | <b>refunded</b>                  | <b>\$</b> |
|  |                     |                     |                  | <b>charged</b>                   | <b>\$</b> |

- a.  A check in the amount of \$690.00 to cover the above fees is enclosed.
- b.  Please charge my Deposit Account No. \_\_\_\_\_ in the amount of \_\_\_\_\_ to cover the above fees. A duplicate copy of this sheet is enclosed.
- c.  The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. 10-0435. A duplicate copy of this sheet is enclosed.
- d.  Fees are to be charged to a credit card. **WARNING:** Information on this form may become public. **Credit card information should not be included on this form.** Provide credit card information and authorization on PTO-2038.

**NOTE:** Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:

**RICHARD D. CONARD, ESQ.**  
**BARNES & THORNBURG**  
 11 SOUTH MERIDIAN STREET  
 INDIANAPOLIS, IN 46204

*Richard D. Conard*  
 \_\_\_\_\_  
 SIGNATURE

**RICHARD D. CONARD**  
 \_\_\_\_\_  
 NAME

**27,321**  
 \_\_\_\_\_  
 REGISTRATION NUMBER

**15 AUGUST 2001 (15.08.01)**  
 \_\_\_\_\_  
 DATE

|   |  |  |
|---|--|--|
| U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR)<br><b>09/913578</b> | INTERNATIONAL APPLICATION NO.<br><b>PCT/US00/02470</b> | ATTORNEY'S DOCKET NUMBER<br><b>20568-68741</b> |
|---|--|--|

|  |              |              |                  |                                  |    |
|--|--------------|--------------|------------------|----------------------------------|----|
| 24. The following fees are submitted:  |              |              |                  | <b>CALCULATIONS PTO USE ONLY</b> |    |
| <b>BASIC NATIONAL FEE ( 37 CFR 1.492 (a) (1) - (5) ) :</b>   |              |              |                  |                                  |    |
| <input type="checkbox"/> Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO . . . . . |              |              | <b>\$1000.00</b> |                                  |    |
| <input type="checkbox"/> International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO . . . . .   |              |              | <b>\$860.00</b>  |                                  |    |
| <input type="checkbox"/> International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO . . . . .  |              |              | <b>\$710.00</b>  |                                  |    |
| <input checked="" type="checkbox"/> International preliminary examination fee (37 CFR 1.482) paid to USPTO but all claims did not satisfy provisions of PCT Article 33(1)-(4) . . . . .  |              |              | <b>\$690.00</b>  |                                  |    |
| <input type="checkbox"/> International preliminary examination fee (37 CFR 1.482) paid to USPTO and all claims satisfied provisions of PCT Article 33(1)-(4) . . . . .   |              |              | <b>\$100.00</b>  |                                  |    |
| <b>ENTER APPROPRIATE BASIC FEE AMOUNT =</b>  |              |              |                  | <b>\$690.00</b>                  |    |
| Surcharge of <b>\$130.00</b> for furnishing the oath or declaration later than <input type="checkbox"/> 20 <input type="checkbox"/> 30 months from the earliest claimed priority date (37 CFR 1.492 (e)).                          |              |              |                  | <b>\$0.00</b>                    |    |
| CLAIMS   | NUMBER FILED | NUMBER EXTRA | RATE             |                                  |    |
| Total claims   | 20 - 20 =    | 0            | x \$18.00        | <b>\$0.00</b>                    |    |
| Independent claims   | 3 - 3 =      | 0            | x \$80.00        | <b>\$0.00</b>                    |    |
| Multiple Dependent Claims (check if applicable). <input type="checkbox"/>  |              |              |                  | <b>\$0.00</b>                    |    |
| <b>TOTAL OF ABOVE CALCULATIONS =</b>   |              |              |                  | <b>\$690.00</b>                  |    |
| <input type="checkbox"/> Applicant claims small entity status. (See 37 CFR 1.27). The fees indicated above are reduced by 1/2.   |              |              |                  | <b>\$0.00</b>                    |    |
| <b>SUBTOTAL =</b>  |              |              |                  | <b>\$690.00</b>                  |    |
| Processing fee of <b>\$130.00</b> for furnishing the English translation later than <input type="checkbox"/> 20 <input type="checkbox"/> 30 months from the earliest claimed priority date (37 CFR 1.492 (f)).                     |              |              |                  | <b>\$0.00</b>                    |    |
| <b>TOTAL NATIONAL FEE =</b>  |              |              |                  | <b>\$690.00</b>                  |    |
| Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31) (check if applicable). <input type="checkbox"/>                                   |              |              |                  | <b>\$0.00</b>                    |    |
| <b>TOTAL FEES ENCLOSED =</b>   |              |              |                  | <b>\$690.00</b>                  |    |
|  |              |              |                  | <b>Amount to be:</b>             | \$ |
|  |              |              |                  | <b>refunded</b>                  |    |
|  |              |              |                  | <b>charged</b>                   | \$ |

- a.  A check in the amount of   \$690.00   to cover the above fees is enclosed.
- b.  Please charge my Deposit Account No. \_\_\_\_\_ in the amount of \_\_\_\_\_ to cover the above fees. A duplicate copy of this sheet is enclosed.
- c.  The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No.   10-0435  . A duplicate copy of this sheet is enclosed.
- d.  Fees are to be charged to a credit card **WARNING:** Information on this form may become public. **Credit card information should not be included on this form.** Provide credit card information and authorization on PTO-2038.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status. COPY

SEND ALL CORRESPONDENCE TO:

**RICHARD D. CONARD, ESQ.**  
**BARNES & THORNBURG**  
**11 SOUTH MERIDIAN STREET**  
**INDIANAPOLIS, IN 46204**

*Richard D. Conard*  
 \_\_\_\_\_  
 SIGNATURE

**RICHARD D. CONARD**  
 \_\_\_\_\_  
 NAME

**27,321**  
 \_\_\_\_\_  
 REGISTRATION NUMBER

**15 AUGUST 2001 (15.08.01)**  
 \_\_\_\_\_  
 DATE

09013578 110501

**PCT/PCT Rec'd 06 NOV 2001**

11 South Meridian Street  
Indianapolis, Indiana 46204  
(317) 236-1313

# BARNES & THORNBURG

## PATENT APPLICATION

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

|  |   |  |
|--|---|--|
| Attorney   | ) |  |
| Docket: 20568-68741  | ) | <u>Certificate Under 37 CFR 1.10</u>   |
| Applicants: OREN, Yair, et al  | ) | Express Mail Label No.: <u>EL 894 013 532 US</u>   |
| Invention: FLEXIBLE AND SCALABLE ARCHITECTURE FOR DWDM NETWORKS IN FIBER RINGS | ) | Date of Deposit <u>06 November 2001</u>  |
| U.S. Serial No: 09/913,578   | ) | I hereby certify that this correspondence is being deposited with the United States Postal Service's "Express Mail Post Office to Addressee" service under 37 CFR 1.10 on the date above and is addressed to the Assistant Commissioner for Patents, Washington, D.C. 20231, Box PCT, Attn: DO/EO/US |
| International Serial No: PCT/US00/02470  | ) | <u>Heather L. Behlmer</u>  |
| International Filing Date: January 31, 2000                                    | ) | Typed of Printed Name of Person Mailing Paper or Fee   |
| Earliest Priority Date: February 15, 1999                                      | ) | <u>Heather L. Behlmer</u>  |
|  | ) | Signature of Person Mailing Paper or Fee   |

## SECOND PRELIMINARY AMENDMENT

Assistant Commissioner  
for Patents  
Box PCT  
Washington, D.C. 20231

Attn: DO/EO/US

Sir:

Prior to substantive examination, please amend the claims as follows:

6. (Amended) A fiber optic network including the node of claim 1 [, 2, 3, 4 or 5] and further including a second node, the second node including a first device for converting a first optical signal at a first frequency carried by the network into a first electrical signal, the second node further including a second device for demodulating first information from the first electrical signal modulated on the first optical signal, the second node further including a third device for modulating second information on a second electrical signal, and the second node further including a fourth device for converting the second information modulated on the second electrical signal into a second optical signal at the first frequency.

Please cancel claims 17-20 without prejudice. These claims were submitted by way of the First Preliminary Amendment filed 15 August 2001.

Please add new claims 21-24 as follows:

21. (New) A fiber optic network including the node of claim 2 and further including a second node, the second node including a first device for converting a first optical signal at a first frequency carried by the network into a first electrical signal, the second node further including a second device for demodulating first information from the first electrical signal modulated on the first optical signal, the second node further including a third device for modulating second information on a second electrical signal, and the second node further including a fourth device for converting the second information modulated on the second electrical signal into a second optical signal at the first frequency.

22. (New) A fiber optic network including the node of claim 3 and further including a second node, the second node including a first device for converting a first optical signal at a first frequency carried by the network into a first electrical signal, the second node further including a second device for demodulating first information from the first electrical signal modulated on the first optical signal, the second node further including a third device for modulating second information on a second electrical signal, and the second node further including a fourth device for converting the second information modulated on the second electrical signal into a second optical signal at the first frequency.

23. (New) A fiber optic network including the node of claim 4 and further including a second node, the second node including a first device for converting a first optical signal at a first frequency carried by the network into a first electrical signal, the second node further including a second device for demodulating first information from the first electrical signal modulated on the first optical signal, the second node further including a third device for modulating second information on a second electrical signal, and the second node further including a fourth device for converting the second information modulated on the second electrical signal into a second optical signal at the first frequency.

24. (New) A fiber optic network including the node of claim 5 and further including a second node, the second node including a first device for converting a first optical signal at a first frequency carried by the network into a first electrical signal, the second node

further including a second device for demodulating first information from the first electrical signal modulated on the first optical signal, the second node further including a third device for modulating second information on a second electrical signal, and the second node further including a fourth device for converting the second information modulated on the second electrical signal into a second optical signal at the first frequency.

#### REMARKS

A clean copy of the amended claim is enclosed on a separate sheet. With the preliminary amendment filed with the application, Applicants sought to delete multiple dependencies. However, Applicants neglected to delete the multiple dependency of claim 6. This was pointed out to Applicants in the notice to file the signed declaration, a copy of which is submitted herewith with the RESPONSE TO NOTIFICATION OF MISSING REQUIREMENTS UNDER 35 U. S. C. 371. This second preliminary amendment is submitted to correct that oversight. With the entry of the foregoing amendments, the application is believed to be in condition for examination and allowance. Consideration of the claims, leading to their allowance and passage of the application to issuance, is respectfully requested.

Please charge any fees that might be due in connection with this Second Preliminary Amendment to our undersigned counsel's deposit account 10-0435 with reference to file 20568-68741. An extra copy of this authorization is enclosed for that purpose.

Respectfully submitted,



Richard D. Conard  
Atty. Reg. No. 27,321  
Attorney for Applicant

RDC/hls/412051  
Indianapolis, Indiana 46204  
(317) 231-7285

## CLEAN COPY OF AMENDED CLAIM

6. (Amended) A fiber optic network including the node of claim 1 and further including a second node, the second node including a first device for converting a first optical signal at a first frequency carried by the network into a first electrical signal, the second node further including a second device for demodulating first information from the first electrical signal modulated on the first optical signal, the second node further including a third device for modulating second information on a second electrical signal, and the second node further including a fourth device for converting the second information modulated on the second electrical signal into a second optical signal at the first frequency.

**BARNES&THORNBURG**

09/09 13 578 11 09 10 8  
09/915578  
JG12 Ref: 11 SOUTH Meridian Street  
Indianapolis, Indiana 46204  
(317) 236-1313  
15 AUG 2001

PATENT APPLICATION

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

|   |   |  |
|---|---|--|
| Attorney                                    | ) |  |
| Docket: 20568-68741                         | ) | <u>Certificate Under 37 CFR 1.10</u>               |
|   | ) | Express Mail Label No.: <u>EL 504 448 901 US</u>   |
| Applicants: OREN, Yair, et al               | ) | Date of Deposit: <u>15 August 2001</u>             |
|   | ) | I hereby certify that this correspondence is being |
| Invention: FLEXIBLE AND SCALABLE            | ) | deposited with the United States Postal Service's  |
| ARCHITECTURE FOR DWDM                       | ) | "Express Mail Post Office to Addressee" service    |
| NETWORKS IN FIBER RINGS                     | ) | under 37 CFR 1.10 on the date above and is         |
|   | ) | addressed to the Assistant Commissioner for        |
| U.S. Serial No: Unknown                     | ) | Patents, Washington, D C 20231, Box PCT, Attn      |
|   | ) | DO/EO/US   |
| International Serial No: PCT/US00/02470     | ) | <u>Heather L. Shellhorn</u>                        |
|   | ) | Typed of Printed Name of Person Mailing Paper or   |
| International Filing Date: January 31, 2000 | ) | Fee  |
|   | ) | <u>H. Shellhorn</u>                                |
| Earliest Priority Date: February 15, 1999   | ) | Signature of Person Mailing Paper or Fee           |
|   | ) |  |
|   | ) |  |
|   | ) |  |
|   | ) |  |

PRELIMINARY AMENDMENT

Attention: DO/EO/US  
Box PCT  
Assistant Commissioner for Patents  
Washington, D.C. 20231

Sir:

Prior to substantive examination, please amend the claims as follows:

12. (Amended) The apparatus of [any preceding claim] claim 1 wherein the fiber optic network includes a closed loop optical fiber, one of the first-mentioned nodes and at least one of the second nodes coupled to the closed loop optical fiber.

13. (Amended) The apparatus of [any preceding claim] claim 1 wherein the fiber optic network includes two closed loop optical fibers for carrying the first optical signal in opposite directions, each node being coupled to both optical fibers.

14. (Amended) The apparatus of [any preceding claim] claim 1 wherein the two closed loop optical fibers also carry the third optical signal in the two opposite directions.

Please add claims 15-20 as follows:



15. The apparatus of claim 2 wherein the fiber optic network includes a closed loop optical fiber, one of the first-mentioned nodes and at least one of the second nodes coupled to the closed loop optical fiber.

16. The apparatus of claim 3 wherein the fiber optic network includes a closed loop optical fiber, one of the first-mentioned nodes and at least one of the second nodes coupled to the closed loop optical fiber.

17. The apparatus of claim 4 wherein the fiber optic network includes a closed loop optical fiber, one of the first-mentioned nodes and at least one of the second nodes coupled to the closed loop optical fiber.

18. The apparatus of claim 5 wherein the fiber optic network includes a closed loop optical fiber, one of the first-mentioned nodes and at least one of the second nodes coupled to the closed loop optical fiber.

19. The apparatus of claim 6 wherein the fiber optic network includes a closed loop optical fiber, one of the first-mentioned nodes and at least one of the second nodes coupled to the closed loop optical fiber.

20. The apparatus of claim 7 wherein the fiber optic network includes a closed loop optical fiber, one of the first-mentioned nodes and at least one of the second nodes coupled to the closed loop optical fiber.

REMARKS

Clean copies of the amended claims are enclosed on a separate sheet. With the entry of the foregoing amendments, the application is believed to be in condition for examination and allowance. Consideration of the claims, leading to their allowance and passage of the application to issuance, is respectfully requested.

Respectfully submitted,



Richard D. Conard  
 Atty. Reg. No. 27,321  
 Attorney for Applicant

RDC/hls/397351  
 Indianapolis, Indiana 46204  
 (317) 231-7285

12. (Amended) The apparatus of claim 1 wherein the fiber optic network includes a closed loop optical fiber, one of the first-mentioned nodes and at least one of the second nodes coupled to the closed loop optical fiber.

13. (Amended) The apparatus of claim 1 wherein the fiber optic network includes two closed loop optical fibers for carrying the first optical signal in opposite directions, each node being coupled to both optical fibers.

14. (Amended) The apparatus of claim 1 wherein the two closed loop optical fibers also carry the third optical signal in the two opposite directions.

09/913578

WO 00/48347

PCT/US00/02470

PTO/PCT Rec'd 15 AUG 2001

FLEXIBLE AND SCALABLE ARCHITECTURE  
FOR DWDM NETWORKS IN FIBER RINGS

Field of the Invention

5           The present invention relates to methods and devices for providing flexible and scalable architecture in networks. It is disclosed in the context of fiber optic communication networks, but is believed to be useful in other applications as well.

Disclosure of the Invention

10           According to an aspect of the invention, a node for a fiber optic communication network includes a first device for converting a first optical signal at a first frequency carried by the network into a first electrical signal, a second device for demodulating from the first electrical signal first information modulated on the first optical signal, a third device for modulating on a second electrical signal second  
15 information, a fourth device for converting the second information modulated on the second electrical signal into a second optical signal at the first frequency, a fifth device for providing a third optical signal at a second frequency and a sixth device for multiplexing the second and third optical signals and placing the multiplexed second and third optical signals on the network. The third optical signal has third information  
20 modulated on it.

          Illustratively according to this aspect of the invention, the network further carries a fourth optical signal at the second frequency. The apparatus further includes a seventh device for converting the fourth optical signal into a third electrical signal, and an eighth device for demodulating from the third electrical signal fourth information  
25 modulated on the fourth optical signal.

          Further illustratively according to this aspect of the invention, the apparatus includes a ninth device for providing a fifth optical signal at a third frequency. The fifth optical signal has fifth information modulated on it. The sixth device multiplexes the second, third and fifth optical signals and places the multiplexed second,  
30 third and fifth optical signals on the network.

2-

Additionally illustratively according to this aspect of the invention, the network further carries a sixth optical signal at the third frequency. The apparatus further includes a tenth device for converting the sixth optical signal into a fourth electrical signal, and an eleventh device for demodulating from the fourth electrical signal sixth information modulated on the sixth optical signal.

Illustratively according to this aspect of the invention, the apparatus further includes a seventh device for providing a fourth optical signal at a third frequency. The fourth optical signal has fourth information modulated on it. The sixth device multiplexes the second, third and fourth optical signals and places the multiplexed second, third and fourth optical signals on the network.

According to another aspect of the invention, a node for a fiber optic communication network includes a first device for converting a first optical signal at a first frequency carried by the network into a first electrical signal, a second device for demodulating first information from the first electrical signal modulated on the first optical signal, a third device for modulating second information on a second electrical signal, and a fourth device for converting the second information modulated on the second electrical signal into a second optical signal at the first frequency.

Illustratively according to this aspect of the invention, the network further carries a third optical signal at a second frequency. The apparatus further includes a fifth device for converting the third optical signal into a third electrical signal having third information modulated on it.

Further illustratively according to the invention, the apparatus includes a sixth device for modulating fourth information on a fourth electrical signal, and a seventh device for converting the fourth information modulated on the fourth electrical signal into a fourth optical signal at the second frequency and placing the multiplexed second and fourth optical signals on the network.

Illustratively according to the invention, a fiber optic network includes a node of the first type described above and one or more nodes of the second type described above.

3-

Illustratively according to the invention, the fiber optic network includes a closed loop optical fiber. One node of the first type described above and one or more nodes of the second type described above are coupled to the closed loop optical fiber.

Further illustratively according to the invention, the fiber optic network includes two closed loop optical fibers, each carrying a copy of the signals flowing in the network in opposite directions. Each node is coupled to both optical fibers to receive from the opposite directions two copies of the signals flowing in the network.

#### Brief Description of the Drawings

10 The invention may best be understood by referring to the following detailed descriptions of illustrative embodiments, and the accompanying drawings which illustrate the invention. In the drawings:

Fig. 1 illustrates a highly simplified block diagram of a network according to the present invention;

15 Fig. 2 illustrates a highly simplified block diagram of a component of a network according to the present invention;

Fig. 3 illustrates a highly simplified block diagram of a component of a network according to the present invention;

20 Fig. 4 illustrates a functional block diagram of a possible component of a network according to the present invention;

Fig. 5 illustrates a functional block diagram of a possible component of a network according to the present invention;

Figs. 6-8 illustrate the operation of certain possible components of a network according to the present invention;

25 Fig. 9 illustrates a functional block diagram of a possible component of a network according to the present invention;

Fig. 10 illustrates a functional block diagram of a component of a network according to the present invention;

30 Fig. 11 illustrates a functional block diagram of a component of a network according to the present invention;

4-

Fig. 12 illustrates a functional block diagram of a component of a network according to the present invention;

Fig. 13 illustrates a functional block diagram of a component of a network according to the present invention; and,

5 Fig. 14 illustrates a functional block diagram of a component of a network according to the present invention.

#### Detailed Descriptions of Illustrative Embodiments

In order to understand the invention, it is helpful to outline certain characteristics of a typical system which incorporates the invention. Referring to Fig. 1, a network 50 includes an arbitrary number of nodes 52 is interconnected in a ring by a pair of optical fibers 54. The data carriers in the optical fibers 54 are generated by an arbitrary number, N, of, for example, laser diodes, providing a respective arbitrary number of wavelengths  $\lambda_1, \lambda_2, \dots \lambda_N, \lambda_{SRC}$  in, for example, the 1550 nm and/or 1310 nm bands. These optical carrier sources provide the optical channels interconnecting the network 50 nodes 52, and these channels, or wavelengths  $\lambda_1, \lambda_2, \dots \lambda_N, \lambda_{SRC}$ , are carried in a single fiber 54 using Dense Wavelength Division Multiplexing (DWDM) technology. Each such wavelength  $\lambda_1, \lambda_2, \dots \lambda_N, \lambda_{SRC}$  is hereinafter sometimes referred to as an optical channel.

20 It is not essential to an implementation of the invention that a particular bit rate or range of bit rates be employed, and so the bit rate of each optical channel  $\lambda_1, \lambda_2, \dots \lambda_N, \lambda_{SRC}$  is arbitrary and independent of the rates of other channels  $\lambda_1, \lambda_2, \dots \lambda_N, \lambda_{SRC}$ . The protocol used by each optical channel  $\lambda_1, \lambda_2, \dots \lambda_N, \lambda_{SRC}$  is arbitrary and independent of the protocol(s) used by other channels  $\lambda_1, \lambda_2, \dots \lambda_N, \lambda_{SRC}$ .

25 Examples of various protocols which may be implemented in various ones of the channels  $\lambda_1, \lambda_2, \dots \lambda_N, \lambda_{SRC}$  carried on systems constructed according to the invention include SONET/SDH, ATM and IP. In the illustrated embodiments, all channels  $\lambda_1, \lambda_2, \dots \lambda_N, \lambda_{SRC}$  are assumed to be using SONET/SDH framing. Channels  $\lambda_1, \lambda_2, \dots \lambda_N, \lambda_{SRC}$  which use different protocols, ATM and IP, for example, are simply mapped into the SONET/SDH frames using established standards

30

5--

and techniques. Both the hub node 52-1 and the terminal nodes 52-2 have the capability to effect the appropriate protocol processing on both the upstream traffic and the downstream traffic.

The invention provides cost-effective architectures for DWDM-based access networks 50 implemented over optical fiber 54 rings. Such networks 50 can carry 5 diverse types of traffic (for example, SONET, ATM, IP, and so on) and even mix different types of traffic in the same optical fiber 54 rings. One of the nodes 52 is designated the hub node 52-1. The other nodes 52 are referred to as terminal nodes 52-2. The traffic pattern in the network 50 is such that terminal nodes 52-2 communicate 10 predominantly with the hub node 52-1, but sometimes with each other. Hub node 52-1-to-terminal node 52-2 traffic is sometimes referred to herein as downstream traffic. Terminal node 52-2-to-hub node 52-1 traffic is sometimes referred to herein as upstream traffic.

According to the invention, a specific optical channel  $\lambda$ SRC is used as a 15 Shared Ring Channel (SRC).  $\lambda$ SRC is optically dropped and re-generated by each node 52. In the process of dropping and regenerating  $\lambda$ SRC, the terminal nodes 52-2 can add in and drop their own traffic. The method used to multiplex the traffic of the different nodes 52 on  $\lambda$ SRC depends on the protocol being used. The hub node 52-1 can drop and demultiplex the traffic it receives on  $\lambda$ SRC into the separate streams generated by each 20 terminal node 52-2, and likewise can multiplex and add the data streams intended for the different terminal nodes 52-2. The wavelength  $\lambda$ SRC may be, for example, 1310nm, 1510nm, or any other optical wavelength defined by the ITU grid. A cost-effective implementation uses the 1310nm wavelength for  $\lambda$ SRC. The components for the 1310nm wavelength are widely available and relatively inexpensive.

25 The network 50 control channel, used for management and fault reporting, is also carried by  $\lambda$ SRC. Because  $\lambda$ SRC is dropped and added at each node 52, it will be appreciated that control information may flow from any node 52 to any other node 52. For example, the hub node 52-1 can insert into the network 50 control information intended for any subset of the terminal nodes 52-2.

6-

The method used to multiplex the control information and the different data channels on  $\lambda$ SRC depends on the protocol(s) being used in the network 50. One approach, applicable when the data channels in the network 50 use SONET/SDH framing, is to have the control channel use the DCC bytes in the section overhead of the SONET/SDH signal. Another approach, applicable to the ATM protocol, is to assign a specific ATM VC to the control flow, and other VCs or VPs to the upstream channels.

In addition to  $\lambda$ SRC, multiple optical channels  $\lambda_1, \lambda_2, \dots, \lambda_N$  can be used to increase the bandwidth capacity from the hub node 52-1 to specific terminal nodes 52-2. Each terminal node 52-2 can be connected to one or more optical channels  $\lambda_K, \lambda_L, \dots, \lambda_P, 1 \leq K, L, \dots, P \leq N, K \neq L \neq \dots, P$ . The hub node 52-1 is connected to all optical channels  $\lambda_1, \lambda_2, \dots, \lambda_N$ . An optical channel  $\lambda_1, \lambda_2, \dots, \lambda_N$  can be shared among multiple terminal nodes 52-2. An optical channel  $\lambda_1, \lambda_2, \dots, \lambda_N$  can be either symmetric, that is, it carries both hub node 52-1-to-terminal node 52-2 and terminal node 52-2-to-hub node 52-1 traffic, or asymmetric, that is, it carries only hub node 52-1-to-terminal node 52-2 traffic. The bit rate(s)  $f_K, f_L, \dots, f_P$  of the optical channel(s)  $\lambda_K, \lambda_L, \dots, \lambda_P$  intended for a specific terminal node 52-2 can be matched to the bandwidth requirements of that terminal node 52-2, and is (are) independent of the bit rates used by other optical channels.

Protection against certain network 50 and equipment failures is provided by using two parallel fiber optic rings 56, 58 which carry their traffic in opposite directions. Where each signal is transmitted in both directions, the receiver can select the best received copy (similar to UPSR in SONET/SDH rings). The two directions are sometimes referred to herein as west-to-east (fiber 56) and east-to-west (fiber 58).

Thus, the following three types of terminals can all exist on the same fiber optic ring network 50: shared ring terminals, which transmit and receives all their traffic on  $\lambda$ SRC; asymmetric terminals, which transmit all their traffic on  $\lambda$ SRC and may receive traffic from both  $\lambda$ SRC and one or more associated optical channels  $\lambda_K, \lambda_L, \dots, \lambda_P$ ; and, symmetric terminals, which can transmit and receive traffic both on  $\lambda$ SRC and on one or more associated symmetric optical channels  $\lambda_K, \lambda_L, \dots, \lambda_P$ . Shared ring terminals are typically less expensive than asymmetric terminals. Asymmetric terminals,



7-

in turn, are typically less expensive than symmetric terminals. This commends the following strategy for a network 50 operator deploying rings based upon this architecture. Initially, when demand at all terminal nodes 52-2 is relatively low, shared ring terminals are deployed at each such site, and a hub system is provided at the hub node 52-1. When the bandwidth requirements of a specific terminal node 52-2 increase, one or more dedicated optical channels  $\lambda K, \lambda L, \dots \lambda P$  can be established between this terminal node 52-2 and the hub node 52-1, with this terminal node 52-2's system upgraded to a symmetric or asymmetric terminal, depending upon whether the traffic pattern between the hub node 52-1 and this terminal node 52-2 is symmetric or asymmetric, respectively. This network 50 architecture combines relatively low entry cost with the ability to scale each terminal node 52-2's capacity upward when and where required. This architecture permits SRC terminals, asymmetric terminals and symmetric terminals all to reside on the same ring. The upgrading of a terminal node 52-2 from a shared ring terminal to an asymmetric or symmetric terminal can be accomplished while the node 52-2 is in service, that is, without interrupting the flow of traffic, and without requiring any change in any other terminal node.

Fig. 2 illustrates a high-level functional diagram of terminal nodes 52-2. A processing subsystem 60 provides protocol processing appropriate to a particular application. Examples include SONET/SDH multiplexers and ATM multiplexers. The processing subsystem 60 provides electrical signals to an optical subsystem 62, to be transmitted on  $\lambda SRC$  and potentially on one or more associated dedicated optical channels  $\lambda K, \lambda L, \dots \lambda P$ , and receives electrical signals derived from  $\lambda SRC$  and potentially the associated dedicated optical channel(s)  $\lambda K, \lambda L, \dots \lambda P$ . The processing subsystem 60 typically also has external ports of different types in order to connect external devices which use the transport services of network 50. The optical subsystem 62 implements the optical add/drop function for  $\lambda SRC$  and potentially the optical add/drop function for the optical channel(s)  $\lambda K, \lambda L, \dots \lambda P$  in symmetric and asymmetric terminal types. It also incorporates the required receivers/transmitters. A control subsystem 64 manages, configures and monitors the operation of the processing

and optical subsystems 60, 62, respectively, and handles communications on the control channel.

Fig. 3 illustrates a high-level functional diagram of a hub node 52-1. A processing subsystem 66 provides protocol-related processing functions such as the cross-connect/switching function and protocol processing for wavelengths  $\lambda_1, \lambda_2, \dots \lambda_N, \lambda_{SRC}$  generated by hub node 52-1. In case of a SONET/SDH application, the processing subsystem 66 may provide the functionality of a SONET/SDH cross-connect, as well as all SONET/SDH-related protocol processing. In the case of an ATM application, the processing subsystem 66 may provide the functionality of an ATM VPX/switch and the associated protocol processing. In case of mixed traffic, both SONET cross-connect and ATM switching functionality can be provided simultaneously. The processing subsystem 66 provides to an optical subsystem 68 an electrical channel for each optical channel  $\lambda_1, \lambda_2, \dots \lambda_N$  generated by this node 52-1 as well as for  $\lambda_{SRC}$ . The processing subsystem 66 receives the electrical signals derived from  $\lambda_{SRC}$  and from incoming optical signal  $\lambda_1, \lambda_2, \dots \lambda_N$ . The processing subsystem 66 typically also has external ports of different types in order to connect external devices which use the transport services of the network 50. The optical subsystem 68 has the capability to generate/terminate all the optical channels  $\lambda_1, \lambda_2, \dots \lambda_N$  being used in the network 50. The optical subsystem 68 incorporates multiplexing/demultiplexing functionality for the optical channels  $\lambda_1, \lambda_2, \dots \lambda_N$ , as well as suitable transmitters and receivers. The optical subsystem 68 also provides an optical interface to  $\lambda_{SRC}$ . A control subsystem 70 manages, configures and monitors the operation of the processing and optical subsystems 66, 68, respectively, and handles all communications on the control channel.

As previously noted, a network 50 constructed according to the invention typically includes a pair of parallel optical fibers 54 which carry signals in opposite directions. For each of the three terminal node 52-2 types, shared ring, symmetric and asymmetric, the optical subsystem 62 includes two similar or identical blocks, one operating on the west-to-east fiber 56 and the other on the east-to-west fiber 58. The purpose of having the two identical blocks is to achieve protection and redundancy.

Fig. 4 illustrates a structure for one of the optical subsystem blocks 71 (either west-to-east, 56, or east-to-west, 58) of a shared ring terminal 72. The incoming fiber 54 (Fiber IN) carries an optical signal including one or more wavelengths  $\lambda_1, \lambda_2, \dots, \lambda_N, \lambda_{SRC}$ . Several optical channels  $\lambda_1, \lambda_2, \dots, \lambda_N$  can be present in the signal, and those channels pass through optical subsystem block 71 unchanged. The combined optical signal  $\lambda_1, \lambda_2, \dots, \lambda_N, \lambda_{SRC}$  is coupled through an optical drop component 74 for  $\lambda_{SRC}$ . The optical drop component 74 removes  $\lambda_{SRC}$  from the combined incoming signal  $\lambda_1, \lambda_2, \dots, \lambda_N, \lambda_{SRC}$  and provides  $\lambda_{SRC}$  to an SRC receiver 76. The remaining wavelengths  $\lambda_1, \lambda_2, \dots, \lambda_N$  pass unchanged through the optical drop component 74 to an SRC optical add function 80.

The exact nature of the SRC optical drop component 74 depends on the wavelength used for that channel. Suitable components 74 are commercially available for, for example, 1310nm, 1510nm, or any other optical wavelength defined by the ITU grid. For example, for a 1310nm carrier, an inexpensive coupler may be used to achieve the required functionality.

The SRC receiver 76 converts  $\lambda_{SRC}$  into an electrical signal. Such receivers 76 are commercially available from several vendors. The resulting electrical signal is coupled to an SRC drop function 82, which decomposes the incoming stream into three components, a control component 84, a dropped data component 86 (data intended for the local terminal 52-2), and a through data component 88 (data intended for other nodes 52). The exact nature of the SRC drop function 82 depends on the structure of the signal. In case of a SONET/SDH signal, the control components typically can be stored in the DCC bytes of the section overhead in the SONET/SDH frames. The different data components will reside in different SONET/SDH sub-channels. The decomposition of the incoming stream into control component 84, dropped data component 86, and through data component 88 can be done by commercially available SONET/SDH framing components such as, for example, the SPECTRA devices available from PMC-Sierra. In the case of an ATM or IP signal, the control sub-channel will be carried as a specific VC in an ATM cell flow or a packet flow with a distinct header in an IP packet stream. Likewise the flows belonging to the different data

components will be carried by specific VCs or by IP packets with distinct headers. Suitable hardware is available to effect the required separation. This type of functionality is normally found in any ATM switching system or IP routing system, respectively.

The resulting isolated control component 84 is coupled to the control subsystem 64 (Fig. 2). The resulting isolated dropped data component is coupled to the processing subsystem 60. The through component 88 is coupled to an SRC add function 92. The SRC add function 92 multiplexes the data stream provided by the processing subsystem 60, as well as the control channel originating in the control subsystem 64, with the through channel 88 from the SRC drop function. Again, the exact nature of this multiplexing function depends on the type and format of the signal, as explained for the drop function 82. The SRC add function 92 can be implemented with the same types of components and logical hardware mentioned above. The resulting signal is converted by an SRC transmitter 94 into an optical signal. The type of transmitter 94 required depends on the wavelength  $\lambda_{SRC}$ . Transmitters 94 are commercially available for, for example, 1310nm, 1510nm, and any other optical wavelength defined by the ITU grid.

The optical signal generated by the SRC transmitter 94 is incorporated into the combined optical signal  $\lambda_1, \lambda_2, \dots \lambda_N$  by the optical add function 80 for  $\lambda_{SRC}$ . The resulting Fiber OUT signal contains all pass-through wavelengths  $\lambda_1, \lambda_2, \dots \lambda_N$ , as well as  $\lambda_{SRC}$ , carrying the locally (re)generated signal.

Fig. 5 illustrates a structure for one of the optical subsystem blocks 100 (either on the west-to-east fiber 56 or on the east-to-west fiber 58) for an asymmetric terminal 102. The incoming fiber 54 (Fiber IN) carries an optical signal including multiple wavelengths  $\lambda_1, \lambda_2, \dots \lambda_N, \lambda_{SRC}$ , one or more of which is (are) the specific downstream channel(s)  $\lambda_K, \lambda_L, \dots \lambda_P$  associated with asymmetric terminal 102. Several other wavelengths ( $\lambda_1, \lambda_2, \dots \lambda_N$ )- $\lambda_K, \lambda_L, \dots \lambda_P$  may be present in the signal, and they pass through optical subsystem block 100 unaffected. The combined optical signal  $\lambda_1, \lambda_2, \dots \lambda_N, \lambda_{SRC}$  is coupled to an optical drop component 104 for the wavelength  $\lambda_{SRC}$ . Optical drop component 104 may be of the same configuration as optical drop component 74 described above in connection with the description of the shared ring terminal 72.

11-

An SRC receiver 106 converts  $\lambda_{\text{SRC}}$  into an electrical signal. Such receivers 106 are commercially available from several vendors. The resulting electrical signal is coupled to an SRC drop function 108, which decomposes the incoming stream into a control component 110, a dropped data component 112 (data intended for the local terminal) and a through data component 114 (data intended for other nodes 52). The SRC drop function 108 can be implemented similarly to the SRC drop function 82 described above in connection with the description of the shared ring terminal 72. The resulting isolated control flow 110 is coupled to the control subsystem 64. The resulting isolated dropped data component 112 is coupled to the processing subsystem 60. The through component 114 is coupled to an SRC add function 118.

After passing through the optical drop 104 for  $\lambda_{\text{SRC}}$ , the incoming optical signal  $\lambda_1, \lambda_2, \dots, \lambda_N$  is coupled to an optical drop 120 for the optical channel(s)  $\lambda_K, \lambda_L, \dots, \lambda_P$  assigned to this asymmetric terminal. The optical drop 120 couples the optical channel(s)  $\lambda_K, \lambda_L, \dots, \lambda_P$  associated with this node 52-2 from the combined incoming signal  $\lambda_1, \lambda_2, \dots, \lambda_N$  to a receiver 122. The remaining wavelengths ( $\lambda_1, \lambda_2, \dots, \lambda_N$ )- $\lambda_K, \lambda_L, \dots, \lambda_P$  pass through the receiver 122 unaffected. The optical drop function 120 may either completely remove the optical channel(s)  $\lambda_K, \lambda_L, \dots, \lambda_P$  assigned to this asymmetric terminal 102 from the fiber 56 or 58 (so-called "drop only" functionality) or it may drop (a) "copy(ies)" of the optical channel(s)  $\lambda_K, \lambda_L, \dots, \lambda_P$  assigned to this asymmetric terminal 102 and also permit the wavelength(s)  $\lambda_K, \lambda_L, \dots, \lambda_P$  to continue (so-called "drop and continue" functionality). These two options are illustrated in Figs. 6 and 7, respectively. Of course, although it is not illustrated in the drawings, if any terminal employs drop and continue functionality,  $\lambda_K, \lambda_L, \dots, \lambda_P$ , the "dropped" frequency (ies) will appear in outputs from the optical drop component(s), that is, it (they) will be both "dropped" and "continued."

Drop only functionality (Fig. 6) can be achieved by using optical drop components 120 available from several vendors. It is also possible to use only the drop function of an optical add/drop multiplexer, or OADM. Drop and continue functionality (Fig. 7) can be achieved more cost-effectively by a coupler on the signal path from an optical drop component 104 which splits the signal's energy and couples a portion of that

12-

energy into another fiber 124. This fiber 124 is coupled to an optical band-pass filter 126 that permits only the specified wavelength to pass. This is illustrated in Fig. 8. The described components are commercially available from several vendors.

Receiver(s) 122K(, 122L, . . . 122P) convert(s) the optical signal(s)  $\lambda K($ ,  
5  $\lambda L, . . . \lambda P)$  into (an) electrical signal(s). Such receivers 122 are commercially available from several vendors. The resulting electrical signal(s) is (are) coupled to the processing subsystem 60.

SRC add function 118 multiplexes a data stream coupled from the processing subsystem 60, a control channel 110 coupled from the control subsystem 64  
10 and a through channel 114 coupled from the SRC drop function 108. The SRC add function 118 may be implemented in the same way as SRC add function 92 described in connection with the description of the shared ring terminal 72. The resulting signal is converted by an SRC transmitter 134 into an optical signal  $\lambda SRC$ . The type of SRC transmitter 134 depends on the wavelength  $\lambda SRC$ . Transmitters 134 are commercially  
15 available for, for example, 1310nm, 1510nm, and any other optical wavelength defined by the ITU grid.

The optical signal  $\lambda SRC$  generated by the SRC transmitter 134 is incorporated into the combined optical signal  $\lambda 1, \lambda 2, . . . \lambda N, \lambda SRC$  by an optical add function 136 for the SRC. The resulting Fiber OUT signal  $\lambda 1, \lambda 2, . . . \lambda N, \lambda SRC$   
20 contains all pass-through wavelengths, including  $\lambda SRC$ , carrying the locally (re)generated signal.

Fig. 9 illustrates a structure for one of the optical subsystem blocks 140 (either on west-to-east fiber 56 or on east-to-west fiber 58) for a symmetric terminal 142 according to the invention. The incoming fiber 54 (Fiber IN) carries an optical signal  
25 including various wavelengths  $\lambda 1, \lambda 2, . . . \lambda N, \lambda SRC$  one (or ones) of which is(are) the specific optical channel(s)  $\lambda K(, \lambda L, . . . \lambda P)$  associated with terminal 142. Several other wavelengths ( $\lambda 1, \lambda 2, . . . \lambda N$ )- $\lambda K(, \lambda L, . . . \lambda P)$  may be present in the signal, and they will pass through optical subsystem block 140 unchanged.

The combined optical signal  $\lambda 1, \lambda 2, . . . \lambda N, \lambda SRC$  is coupled to an  
30 optical drop component 144 for  $\lambda SRC$ . Optical drop component 144 may be of the same

configuration as optical drop component 74 described above in connection with the description of the shared ring terminal 72.

An SRC receiver 146 converts  $\lambda_{\text{SRC}}$  into an electrical signal. Such receivers 146 are commercially available from several vendors. The resulting electrical signal is coupled to an SRC drop function 148, which decomposes the incoming stream into a control component 150, a dropped data component 152 (data intended for the local terminal 52-2) and a through data component 154 (data intended for other nodes 52). The SRC drop function 148 can be implemented similarly to the SRC drop function 82 described above in connection with the description of the shared ring terminal 72. The resulting isolated control flow 150 is delivered to the control subsystem 64. The resulting isolated dropped data component 152 is coupled to the processing subsystem 60. The through component 154 is coupled to an SRC add function 158.

After the SRC drop function 148, the incoming signal (without  $\lambda_{\text{SRC}}$ ) is coupled to an optical drop 158 for the optical channel(s)  $\lambda_{\text{K}}, \lambda_{\text{L}}, \dots \lambda_{\text{P}}$ . Optical drop 158 isolates the optical channel(s)  $\lambda_{\text{K}}, \lambda_{\text{L}}, \dots \lambda_{\text{P}}$  associated with this node 52-2 from the combined incoming signal and provides  $\lambda_{\text{K}}, \lambda_{\text{L}}, \dots \lambda_{\text{P}}$  to (a) receiver(s) 160K, 160L,  $\dots$  160P). The remaining wavelengths  $(\lambda_1, \lambda_2, \dots \lambda_{\text{N}}) - \lambda_{\text{K}}, \lambda_{\text{L}}, \dots \lambda_{\text{P}}$  pass through optical drop 158 unchanged. The optical drop function 158 removes the wavelength(s)  $\lambda_{\text{K}}, \lambda_{\text{L}}, \dots \lambda_{\text{P}}$  from the fiber 56 or 58. The exact nature of the optical drop component 158 for the optical channel depends on the wavelength(s)  $\lambda_{\text{K}}, \lambda_{\text{L}}, \dots \lambda_{\text{P}}$  associated with this node 52-2. Suitable components 158 are commercially available for any optical wavelength defined by the ITU grid. The receiver(s) 160K, 160L,  $\dots$  160P) transform(s) the isolated optical channel(s)  $\lambda_{\text{K}}, \lambda_{\text{L}}, \dots \lambda_{\text{P}}$  into (an) electrical signal(s). Such receivers 160 are commercially available from several vendors. The resulting electrical signal(s) is(are) coupled to the processing subsystem 60.

(A) transmitter(s) 162K, 162L,  $\dots$  162P) transform(s) the electrical signal(s) coupled from the processing subsystem 60 into (an) optical signal(s) at the wavelength(s)  $\lambda_{\text{K}}, \lambda_{\text{L}}, \dots \lambda_{\text{P}}$  appropriate for this (these) optical channel(s)  $\lambda_{\text{K}}, \lambda_{\text{L}}, \dots \lambda_{\text{P}}$ . Such transmitters 162 are commercially available from several vendors. The resulting optical signal(s) is (are) then incorporated into the combined optical signal by

(an) optical add component(s) 164K(, 164L, . . . 164P) suitable for wavelength(s)  $\lambda_K$ (,  $\lambda_L$ , . . .  $\lambda_P$ ). Suitable components 164 are commercially available for any optical wavelength(s)  $\lambda_K$ (,  $\lambda_L$ , . . .  $\lambda_P$ ) defined by the ITU grid. The output signal(s) of this (these) component(s) 164K(, 164L, . . . 164P) contains  $\lambda_1, \lambda_2, \dots \lambda_N$ . The optical channel optical drop 158 and optical add 164 functions may be integrated into (an) OADM(s).

SRC add function 158 multiplexes the data stream 152 coupled from the processing subsystem 60, the control channel 150 coupled from the control subsystem 64, and the through channel 154 coupled from the SRC drop function 148. The SRC add function 158 may be implemented in the same way as SRC add function 92 described in connection with the description of the shared ring terminal 72. The resulting signal is converted by an SRC transmitter 168 into an optical signal. The type of transmitter 168 required depends on the wavelength used for the SRC. Transmitters are commercially available for, for example, 1310nm, 1510nm, and any other optical wavelength defined by the ITU grid. The optical signal  $\lambda_{SRC}$  generated by the SRC transmitter 168 is incorporated into the combined optical signal  $\lambda_1, \lambda_2, \dots \lambda_N$  by an optical add function 170 for the SRC. The resulting Fiber OUT signal contains all pass-through wavelengths ( $\lambda_1, \lambda_2, \dots \lambda_N$ )- $\lambda_K$ (,  $\lambda_L, \dots \lambda_P$ ), plus the locally generated optical channel(s)  $\lambda_K$ (,  $\lambda_L, \dots \lambda_P$ ), plus the wavelength  $\lambda_{SRC}$  used for the SRC, carrying the locally (re)generated signal.

As noted above, in all three terminal types 72, 102, 142 a similar optical block 71, 100, 140 is provided on the other fiber 54. In this way, the processing subsystem 60 gets input from both fiber 56 and fiber 58 through their respective optical blocks. In the case of dedicated DWDM channels, the content of these two data streams should be identical unless there is some fault in the network 50 that results in disruption of the signal flow. The processing subsystem 60 must therefore select at any time which input to process and which to discard. The selection is based on the relative quality of the received signals, measured by the performance monitoring provisions of the protocols used in a particular application. The data channel generated by the processing subsystem



15-

60 must be duplicated and transmitted to both optical blocks. This applies to the data traffic on the dedicated optical channel, if used.

The mechanism used for the SRC is somewhat different. Unlike the dedicated optical channels  $\lambda_1, \lambda_2, \dots, \lambda_N$ , which can be seen as logical point-to-point links to the hub 52-1, any node 52 can receive traffic on the SRC from any other node 52 on the ring. In case of a fault anywhere in the network 50, each channel of such traffic will be received either from the east, on fiber 58, or from the west, on fiber 56. It follows that the processing subsystem 60 of a particular node 52-2's terminal must have a selection function for the SRC, that exhibits the following behavior. When no fault that results in disruption of the SRC is present in the network 50, either the east copy (on fiber 58) or the west copy (on fiber 56) of the SRC must be selected. Selection is based on the relative quality of the received signals, measured by the performance monitoring provisions of the protocols used in a particular application. When a fault that results in disruption of the SRC exists, the channels arriving from the east should be combined with those arriving from the west in such a way that one valid copy of each channel is available. This mechanism is similar to that used in SONET path protection, for example, in SONET UPSR rings. The same holds true for the interaction between the control subsystem 64 and the optical subsystem 62 with respect to the control channel. This is illustrated in Fig. 10.

Fig. 11 illustrates a structure for the optical subsystem block 180 that operates on the west-to-east fiber 56 in a hub node 52-1. To achieve protection and redundancy, a similar block operates on the east-to-west fiber 58. The interaction between the two blocks 180 is discussed below. In this example, some terminal nodes 52-2 operate in shared ring mode, meaning the hub 52-1 transmits and receives their traffic exclusively on  $\lambda_{SRC}$ . Three terminal nodes 52-2 (those associated with  $\lambda_1, \lambda_2$  and  $\lambda_N$ ) operate in symmetric mode, while the terminal associated with  $\lambda_3$  operates in asymmetric mode, as evidenced by the fact that there is no receiver for an upstream optical channel for the wavelength  $\lambda_3$ .

The incoming fiber (Fiber IN) carries an optical signal including  $\lambda_{SRC}$  and potentially optical wavelengths  $\lambda_1, \lambda_2, \dots, \lambda_N$  used for upstream channels. The

combined signal first goes through an optical drop component 182 for the wavelength  $\lambda$ SRC. Component 182 may be of the same type as optical drop component 74 described above in connection with shared ring terminal 72.

An SRC receiver 186 converts  $\lambda$ SRC into an electrical signal. Such  
 5 receivers 186 are commercially available from several vendors. The resulting electrical signal is coupled to an SRC drop function 188, which decomposes the incoming stream into a control component 190, a set 192 of upstream channels from all terminal nodes 52-2 (it is assumed that the processing subsystem 66 can break this multiplexed stream into its constituent channels), and a through data component 194 (data intended for other  
 10 nodes 52-2). The SRC drop function 188 can be implemented in the same manner as the SRC drop function 82 described above in connection with the description of the shared ring terminal 72. The resulting isolated control flow 190 is delivered to the control subsystem 70. The resulting isolated upstream channels 192 are coupled to the processing subsystem 66. The through component 194 is coupled to an SRC add  
 15 function 198.

After the optical drop for SRC function, the incoming optical signal without  $\lambda$ SRC is coupled to a DWDM demultiplexer 200. DWDM demultiplexer 200 demultiplexes the DWDM signal into its constituent wavelengths  $\lambda_1, \lambda_2, \dots, \lambda_N$ . Each wavelength is then either coupled to a suitable receiver 202-1, 202-2, 202-4,  $\dots$  202-N  
 20 for  $\lambda_1, \lambda_2, \lambda_4, \dots, \lambda_N$ , respectively, or discarded, as in the case of  $\lambda_3$ , recalling that the terminal node 52-2 associated with  $\lambda_3$  operates in asymmetric mode. Such DWDM demultiplexers 200 are commercially available from several vendors. The receivers 202-1, 202-2, 202-4,  $\dots$  202-N transform their respective isolated DWDM channels  $\lambda_1, \lambda_2, \lambda_4, \dots, \lambda_N$  into electrical signals. Such receivers 202-1, 202-2, 202-4,  $\dots$  202-N are  
 25 commercially available from several vendors. The resulting electrical signals are coupled to the processing subsystem 66.

The electrical downstream channels provided by the processing subsystem 66 are transformed by their respective DWDM transmitters 204-1, 204-2,  $\dots$  204-N into optical signals. The DWDM transmitters 204-1, 204-2,  $\dots$  204-N are components  
 30 suitable for the wavelengths  $\lambda_1, \lambda_2, \dots, \lambda_N$  used for their respective downstream

17-

channels. Such transmitters 204-1, 204-2, . . . 204-N are commercially available from several vendors. The optical signals  $\lambda_1$ ,  $\lambda_2$ , . . .  $\lambda_N$  output by these transmitters are then combined for insertion into west-to-east fiber 56 by a DWDM multiplexer component 206. DWDM multiplexer components 206 are commercially available from several vendors. The output signal of this component contains all the DWDM wavelengths  $\lambda_1$ ,  $\lambda_2$ , . . .  $\lambda_N$  generated by the local transmitters 204-1, 204-2, . . . 204-N. This signal is coupled to an optical add function for SRC 208.

SRC add function 198 combines the multiplexed data stream provided by the processing subsystem 66, the control channel originating in the control subsystem 70, and the through channel from the SRC drop function 188. The resulting signal is converted by an SRC transmitter 210 into an optical signal. The type of transmitter 210 required depends on the wavelength used for the SRC. Transmitters 210 are commercially available for 1310nm, 1510nm, and any other optical wavelength defined by the ITU grid. Transmitter 210 is also coupled to SRC optical add function 208 to combine the optical SRC signal with the optical wavelengths generated by the local transmitters 204-1, 204-2, . . . 204-N. SRC optical add function 208 may be implemented in the same manner as SRC add function 166 described in connection with the description of symmetric terminal 142. The resulting Fiber OUT signal contains all wavelengths  $\lambda_1$ ,  $\lambda_2$ , . . .  $\lambda_N$  used for the downstream channels as well as the wavelength  $\lambda_{SRC}$  used for the SRC.

As previously noted, an optical block 180 similar to the one just described is provided for the east-to-west fiber 58. The protection mechanisms described above for the terminal nodes 52-2, with respect to the dedicated optical channels and the data and control flows on the SRC, also apply to the east-to-west fiber 58. In particular, an independent selection and duplication function is applied to each optical channel in use.

Another embodiment of the invention is a special case of the embodiment described above, in which only shared ring and asymmetric terminals are employed. This embodiment includes an implementation of the hub node optimized for this case. This embodiment is useful for providing unidirectional optical channels. The traffic pattern is, of course, asymmetric in the sense that the volume of downstream traffic is

18-

much higher than the volume of upstream traffic. An example of this type of environment include xDSL traffic in which networks collect traffic from several sites containing DSL concentrators for routing to a regional hub node. ADSL traffic is inherently asymmetric, with downstream bandwidth up to an order of magnitude higher than the upstream bandwidth. Another example of this type of environment is cable modem traffic. Cable networks collect traffic from several sites containing cable modem headends for routing to a regional data hub node. Cable modem traffic is also inherently asymmetric. The required downstream bandwidth for a specific terminal node 52-2 is arbitrary and independent of the bandwidth required for any other terminal node 52-2. The aggregate bandwidth in the network 50 exceeds that which can be handled by any approach that makes use of a single optical channel such as, for example, a prior art SONET/SDH ring, thus commending the use of DWDM.

The hub node 52-1 includes a DWDM transmitter for each DWDM channel in use in the network 50. The hub node 52-1 also includes a multiplexer for combining all of the generated channels into a single fiber. Each terminal node 52-2 has the ability to drop one or more of the downstream channels and terminate the optical signal(s) with (a) suitable receiver(s). The received data stream(s) is (are) then processed. The rate(s) of the downstream channel(s) intended for a specific terminal can be matched to the bandwidth requirements of that terminal. In addition, several terminals may share the same downstream channel(s). This permits better utilization of the downstream channels. A significant advantage of this approach is that it reduces the number and cost of DWDM components. The hub node 52-1 needs one transmitter per channel in the network 50, and a suitable multiplexer. It does not require receivers or a demultiplexer. Each terminal node 52-2 requires a receiver for (each of) its downstream channel(s) and suitable components to drop its channel's (s') wavelength(s) from the network 50, but does not require a transmitter. Thus, this embodiment does not require that each node drop the downstream channels or add them. The optical drop function at the terminal nodes 52-2 is thereby made less expensive, and the optical add function at the terminal nodes 52-2 is eliminated entirely. Each terminal node 52-2 still must be able to drop and add the  $\lambda$ SRC, which requires a suitable receiver and transmitter. As

19-

noted above, if the 1310 nm wavelength is used for  $\lambda$ SRC, the required components are relatively inexpensive.

A specific optical channel  $\lambda$ SRC is used as the SRC to collect upstream traffic from all nodes.  $\lambda$ SRC is optically dropped and re-generated by each node 52. In the process of dropping and regenerating  $\lambda$ SRC, the terminal nodes 52-2 can add their own upstream traffic. The method used to multiplex the traffic of the different nodes 52-2 on  $\lambda$ SRC depends on the protocol being used. The hub node 52-1 can drop and demultiplex the traffic it receives on  $\lambda$ SRC into the separate streams generated by each terminal node 52-2. The wavelength  $\lambda$ SRC may be, for example, 1310 nm, 1510 nm, or any other optical wavelength defined by the ITU grid. Again, a cost-effective implementation uses the 1310 nm wavelength for  $\lambda$ SRC for the reasons previously noted.

The network 50 control channel, used for management and fault reporting, is also carried by  $\lambda$ SRC. Because  $\lambda$ SRC is dropped and added at each node 52, it will be appreciated that control information may flow from any node 52 to any other node 52. For example, the hub node 52-1 can insert into the network 50 control information intended for any subset of the terminal nodes 52-2.

The method used to multiplex the control information and the different data channels on  $\lambda$ SRC depends on the protocol(s) being used in the network 50. As previously noted, and only by way of example, an approach applicable when the data channels in the network 50 use SONET/SDH framing is to have the control channel use the DCC bytes in the section overhead of the SONET/SDH signal. Each specific upstream channel would then use a different SONET/SDH sub-channel. Another approach, applicable to the ATM protocol, is to assign a specific ATM VC to the control flow, and other VCs or VPs to the upstream channels.

Referring now particularly to Fig. 12, the downstream traffic uses unidirectional optical channels  $\lambda_1, \lambda_2, \dots, \lambda_N$ . Specifically, the hub node has a DWDM transmitter 404-1, 404-2,  $\dots$  404-N for each DWDM channel  $\lambda_1, \lambda_2, \dots, \lambda_N$  in use, and a DWDM multiplexer 406 to combine all the generated channels  $\lambda_1, \lambda_2, \dots, \lambda_N$  into a single fiber 54. Each terminal node 52-2 (Fig. 13) has the ability to drop one or more  $\lambda_K, \lambda_L, \dots, \lambda_P$  of the downstream channels  $\lambda_1, \lambda_2, \dots, \lambda_N$  and terminate the optical

20-

signal(s) with (a) suitable receiver(s) 322. The resulting data stream(s) is (are) then processed. The rate(s)  $f_K, f_L, \dots, f_P$  of the downstream channel(s)  $\lambda_K, \lambda_L, \dots, \lambda_P$  intended for a specific terminal 52-2 can be matched to the bandwidth requirements of that terminal 52-2. In addition, several terminals 52-2 may share the same downstream  
5 channel(s)  $\lambda_K, \lambda_L, \dots, \lambda_P$ . This permits greater utilization of the downstream channels  $\lambda_1, \lambda_2, \dots, \lambda_N$ .

As in the first embodiment, protection against certain network 50 and equipment failures is provided by using two parallel fiber optic rings 56, 58 which carry their traffic in opposite directions. Where each signal is transmitted in both directions,  
10 the receiver can select the best received copy (similar to UPSR in SONET/SDH rings).

The high level functional descriptions of the terminal nodes 52-2 and hub node 52-1 are the same as illustrated in Figs. 1 and 2, respectively.

Fig. 13 illustrates structure within the optical subsystem of a terminal node 52-2 that operates on the west-to-east fiber 56. To achieve protection and  
15 redundancy, another similar or identical structure operates on the east-to-west fiber 58. The incoming fiber (Fiber IN) carries an optical signal including  $\lambda_{SRC}$  and the wavelengths  $\lambda_1, \lambda_2, \dots, \lambda_N$ , one or more,  $\lambda_K, \lambda_L, \dots, \lambda_P$ , of which is (are) the specific downstream channel(s) associated with this terminal 52-2. Several other wavelengths ( $\lambda_1, \lambda_2, \dots, \lambda_N$ )- $\lambda_K, \lambda_L, \dots, \lambda_P$  may be present, and these will pass through the  
20 structure illustrated in Fig. 13 and its complement on the east-to-west fiber 58 unchanged. The combined optical signal  $\lambda_1, \lambda_2, \dots, \lambda_N, \lambda_{SRC}$  is coupled to an optical drop component 304 for  $\lambda_{SRC}$ . Component 304 removes the wavelength  $\lambda_{SRC}$  associated with the SRC from the combined incoming signal ( $\lambda_1, \lambda_2, \dots, \lambda_N, \lambda_{SRC}$ ) and provides the isolated SRC wavelength  $\lambda_{SRC}$  to an SRC receiver 306. The remaining  
25 wavelengths  $\lambda_1, \lambda_2, \dots, \lambda_N$  pass through component 304 unchanged. Again, the exact nature of the SRC optical drop component 304 depends on the wavelength  $\lambda_{SRC}$  used for that channel. Suitable components 304 are commercially available for, for example, 1310nm, 1510nm, or any other optical wavelength defined by the ITU grid.

SRC receiver 306 converts  $\lambda_{SRC}$  into an electrical signal. Such receivers  
30 306 are commercially available from several vendors. The resulting electrical signal is

21-

coupled to an SRC drop function 308, which separates the control component in the SRC from the data component. The exact nature of the drop function 308 depends on the structure of the signal. In case of a SONET/SDH framed signal, for example, the SRC drop function 308 must isolate the information contained in the DCC bytes of the section  
5 overhead in the SONET/SDH frames. This can be done by commercially available SONET/SDH framing components such as the SPECTRA or SUNI devices from PMC-Sierra. If the control sub-channel is carried as a specific VC in an ATM cell flow or a specifically addressed packet flow in an IP packet stream, suitable hardware can be devised to effect the required separation functionality. This type of functionality is  
10 normally found in any ATM switching system or IP routing system, respectively. The resulting isolated control flow is delivered to the control subsystem 64 (Fig. 2). The resulting isolated data stream, containing the through traffic, such as, for example, downstream channels of terminals 52-2 other than the illustrated terminal 52-2, is forwarded as is to an SRC add function 318, described below.

15 After passing through the optical drop 304 for  $\lambda_{SRC}$ , the incoming optical signal  $\lambda_1, \lambda_2, \dots, \lambda_N$  is next coupled to (an) optical drop(s) 320 for the optical channel(s)  $\lambda_K, \lambda_L, \dots, \lambda_P$  assigned to the illustrated terminal 52-2. The optical drop(s) 320 couple(s) the optical channel(s)  $\lambda_K, \lambda_L, \dots, \lambda_P$  associated with this node 52-2 from the combined incoming signal  $\lambda_1, \lambda_2, \dots, \lambda_N$  to receiver(s) 322. The remaining  
20 wavelengths ( $\lambda_1, \lambda_2, \dots, \lambda_N$ )- $\lambda_K, \lambda_L, \dots, \lambda_P$  pass through the optical drop function 320 unaffected. The optical drop function 320 may be achieved in different ways, and some options are illustrated in Figs. 5-7.

Receiver(s) 322 convert(s) the optical signal  $\lambda_K, \lambda_L, \dots, \lambda_P$  into (an) electrical signal(s). Such receivers 322 are commercially available from several vendors.  
25 The resulting electrical signal is coupled to the processing subsystem 60.

SRC add function 318 multiplexes a data stream coupled from the processing subsystem 60, a control channel 310 coupled from the control subsystem 64 and a through channel 314 coupled from the SRC drop function 308. The SRC add function 318 may be implemented in the same way as SRC add function 92 described in  
30 connection with the description of the shared ring terminal 72. The resulting signal is

22-

converted by an SRC transmitter 334 into an optical signal  $\lambda_{\text{SRC}}$ . The type of SRC transmitter 334 depends on the wavelength  $\lambda_{\text{SRC}}$ . Transmitters 334 are commercially available for, for example, 1310nm, 1510nm, and any other optical wavelength defined by the ITU grid.

5           The optical signal  $\lambda_{\text{SRC}}$  generated by the SRC transmitter 334 is incorporated into the combined optical signal ( $\lambda_1, \lambda_2, \dots, \lambda_N$ ) by an optical add function 336 for the SRC. The resulting Fiber OUT signal ( $\lambda_1, \lambda_2, \dots, \lambda_N$ ) contains all pass-through wavelengths, including  $\lambda_{\text{SRC}}$ , carrying the locally (re)generated signal.

          As noted above, a similar optical block is provided on the east-to-west  
10 fiber 58. In this way, the processing subsystem 60 gets input from both fiber 56 and fiber 58 through their respective optical blocks. In the case of the downstream DWDM channels, the content of these two data streams should be identical unless there is some fault in the network 50 that results in disruption of the signal flow. The processing subsystem 60 must therefore select at any time which input to process and which to  
15 discard. The selection is based on the relative quality of the received signals, measured by the performance monitoring provisions of the protocols used in a particular application. As before, any node 52 can receive traffic on the SRC from any other node 52 on the ring. In case of a fault anywhere in the network 50, each channel of such traffic will be received either from the east, on fiber 58, or from the west, on fiber 56. It  
20 follows that the processing subsystem 60 of a particular node 52-2's terminal must have a selection function for the SRC, that exhibits the following behavior. When no fault that results in disruption of the SRC is present in the network 50, either the east copy (on fiber 58) or the west copy (on fiber 56) of the SRC must be selected. Selection is based on the relative quality of the received signals, measured by the performance monitoring  
25 provisions of the protocols used in a particular application. When a fault that results in disruption of the SRC exists, the channels arriving from the east should be combined with those arriving from the west in such a way that one valid copy of each channel is available. Again, this mechanism is similar to that used in SONET path protection, for example, in SONET UPSR rings. The same holds true for the interaction between the



control subsystem 64 and the optical subsystem 62 with respect to the control channel. This is illustrated in Fig. 14.

Fig. 12 illustrates a structure for the optical subsystem block 380 that operates on the west-to-east fiber 56 in a hub node 52-1 according to the invention. To achieve protection and redundancy, a similar block 380 operates on the east-to-west fiber 58. The interaction between the two blocks 380 is discussed below.

The incoming fiber (Fiber IN) carries an optical signal including the SRC wavelength  $\lambda_{\text{SRC}}$  and potentially optical wavelengths  $\lambda_1, \lambda_2, \dots, \lambda_N$  used for downstream channels. The downstream channel wavelengths were originally transmitted by the hub node 52-1 and presumably have been dropped and continued by terminal nodes 52-2 along the network 50. In any case, they have no further use once they reach the hub node 52-1, and are discarded. The combined signal is coupled to an optical drop component 382 for  $\lambda_{\text{SRC}}$ . Component 382 may be of the same type as optical drop component 74 described above in connection with shared ring terminal 72.

An SRC receiver 386 converts  $\lambda_{\text{SRC}}$  into an electrical signal. Such receivers 386 are commercially available from several vendors. The resulting electrical signal is coupled to an SRC drop function 388, which decomposes the incoming stream into a control channel 390 and a set 392 of upstream channels from all terminal nodes 52-2. Again, the recovered signals in the channels 392 are of no further use and are discarded. The SRC drop function 388 can be implemented in the same manner as the SRC drop function 82 described above in connection with the description of the shared ring terminal 72. The resulting isolated control flow 390 is delivered to the control subsystem 70 (Fig. 3).

The electrical downstream channels provided by the processing subsystem 66 are transformed by their respective transmitters 404-1, 404-2,  $\dots$  404-N into optical signals. The DWDM transmitters 404-1, 404-2,  $\dots$  404-N are components suitable for the wavelengths  $\lambda_1, \lambda_2, \dots, \lambda_N$  used for their respective downstream channels. Such transmitters 404-1, 404-2,  $\dots$  404-N are commercially available from several vendors. The optical signals  $\lambda_1, \lambda_2, \dots, \lambda_N$  output by these transmitters are then combined for insertion into west-to-east fiber 56 by DWDM multiplexer component 406. DWDM

24-

5 multiplexer components 406 are commercially available from several vendors. The output signal of this component contains all the DWDM wavelengths  $\lambda_1, \lambda_2, \dots, \lambda_N$  generated by the local transmitters 404-1, 404-2,  $\dots$  404-N. An SRC add function 408 prepares the data stream provided by the control channel 190 for conversion into an optical signal by an SRC transmitter 410. The type of transmitter 410 required depends on the wavelength used for the SRC. Transmitters 410 are commercially available for 1310nm, 1510nm, and any other optical wavelength defined by the ITU grid. Transmitter 410 is coupled to an SRC optical add function 418 to combine the optical SRC signal with the DWDM wavelengths generated by the local transmitters 404-1, 404-10 2,  $\dots$  404-N. SRC optical add function 408 may be implemented in the same manner as SRC add function 166 described in connection with the description of symmetric terminal 142.

The resulting Fiber OUT signal contains all wavelengths  $\lambda_1, \lambda_2, \dots, \lambda_N$  used for the downstream channels, as well as  $\lambda_{SRC}$ .

15 As previously noted, an optical block 380 similar to the one just described is provided for the east-to-west fiber 58. As the hub 52-1 does not receive any DWDM channels, it does not need to effect any selection function of DWDM channels for the purposes of protection. It does need, however, to transmit its downstream channels in both directions, in order to provide protection for the terminals 52-2. This is achieved by  
20 duplicating the downstream data channels generated by the processing subsystem 66 to both optical blocks 380. As in the case of the terminal node 52-2, a different mechanism is used for protecting the SRC. The required mechanism is identical to that described for the terminal node 52-2.

Claims

1. A node for a fiber optic communication network, the node including a first device for converting a first optical signal at a first frequency carried by the network into a first electrical signal, a second device for demodulating from the first electrical signal first information modulated on the first optical signal, a third device for modulating on a second electrical signal second information, a fourth device for converting the second information modulated on the second electrical signal into a second optical signal at the first frequency, a fifth device for providing a third optical signal at a second frequency, the third optical signal having third information modulated on it, and a sixth device for multiplexing the second and third optical signals and placing the multiplexed second and third optical signals on the network.

2. The apparatus of claim 1 wherein the network further carries a fourth optical signal at the second frequency, the apparatus further including a seventh device for converting the fourth optical signal into a third electrical signal, and an eighth device for demodulating from the third electrical signal fourth information modulated on the fourth optical signal.

3. The apparatus of claim 2 further including a ninth device for providing a fifth optical signal at a third frequency, the fifth optical signal having fifth information modulated on it, the sixth device multiplexing the second, third and fifth optical signals and placing the multiplexed second, third and fifth optical signals on the network.

4. The apparatus of claim 3 wherein the network further carries a sixth optical signal at the third frequency, the apparatus further including a tenth device for converting the sixth optical signal into a fourth electrical signal, and an eleventh device for demodulating from the fourth electrical signal sixth information modulated on the sixth optical signal.

5. The apparatus of claim 1 further including a seventh device for providing a fourth optical signal at a third frequency, the fourth optical signal having fourth information modulated on it, the sixth device multiplexing the second, third and

26-

fourth optical signals and placing the multiplexed second, third and fourth optical signals on the network.

6. A fiber optic network including the node of claim 1, 2, 3, 4 or 5 and further including a second node, the second node including a first device for  
5 converting a first optical signal at a first frequency carried by the network into a first electrical signal, the second node further including a second device for demodulating first information from the first electrical signal modulated on the first optical signal, the second node further including a third device for modulating second information on a second electrical signal, and the second node further including a fourth device for  
10 converting the second information modulated on the second electrical signal into a second optical signal at the first frequency.

7. The apparatus of claim 6 wherein the network further carries a third optical signal at a second frequency, the second node further including a fifth device for converting the third optical signal into a third electrical signal having third  
15 information modulated on it.

8. The apparatus of claim 7, the second node further including a sixth device for modulating fourth information on a fourth electrical signal, and the second node further including a seventh device for converting the fourth information modulated on the fourth electrical signal into a fourth optical signal at the second frequency and  
20 placing the multiplexed second and fourth optical signals on the network.

9. A node for a fiber optic communication network, the node including a first device for converting a first optical signal at a first frequency carried by the network into a first electrical signal, a second device for demodulating first information from the first electrical signal modulated on the first optical signal, a third  
25 device for modulating second information on a second electrical signal, and a fourth device for converting the second information modulated on the second electrical signal into a second optical signal at the first frequency.

10. The apparatus of claim 9 wherein the network further carries a third optical signal at a second frequency, further including a fifth device for converting

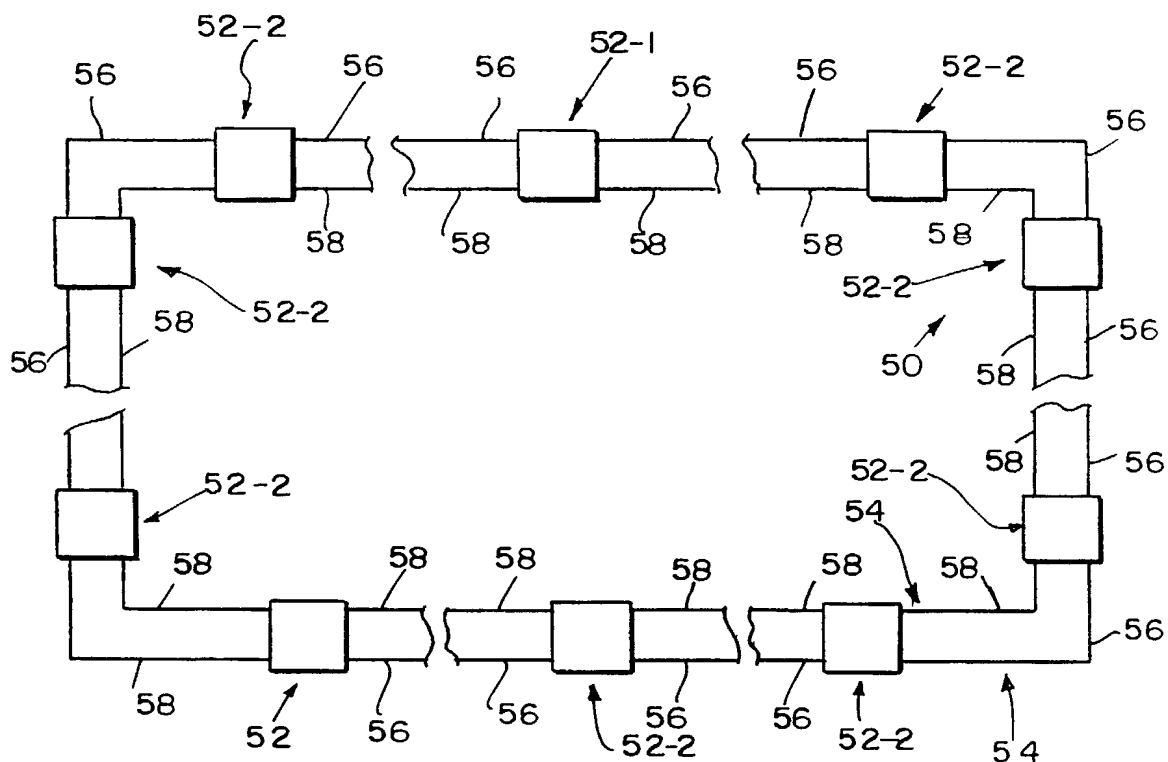
the third optical signal into a third electrical signal having third information modulated on it.

11. The apparatus of claim 10 further including a sixth device for modulating fourth information on a fourth electrical signal, and a seventh device for  
 5 converting the fourth information modulated on the fourth electrical signal into a fourth optical signal at the second frequency and placing the multiplexed second and fourth optical signals on the network.

12. The apparatus of any preceding claim wherein the fiber optic  
 network includes a closed loop optical fiber, one of the first-mentioned nodes and at least  
 10 one of the second nodes coupled to the closed loop optical fiber.

13. The apparatus of any preceding claim wherein the fiber optic network includes two closed loop optical fibers for carrying the first optical signal in opposite directions, each node being coupled to both optical fibers.

14. The apparatus of any preceding claim wherein the two closed loop  
 15 optical fibers also carry the third optical signal in the two opposite directions.



*FIG. 1*

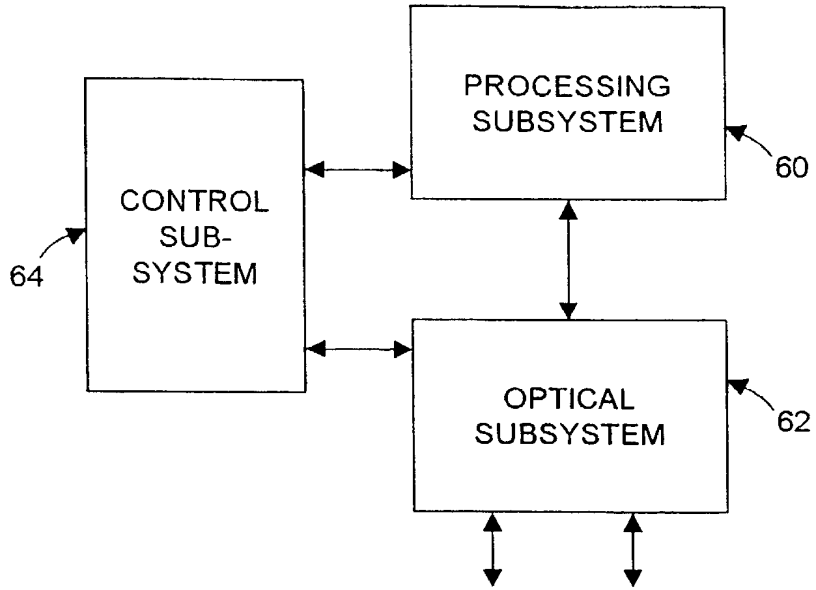


FIG. 2

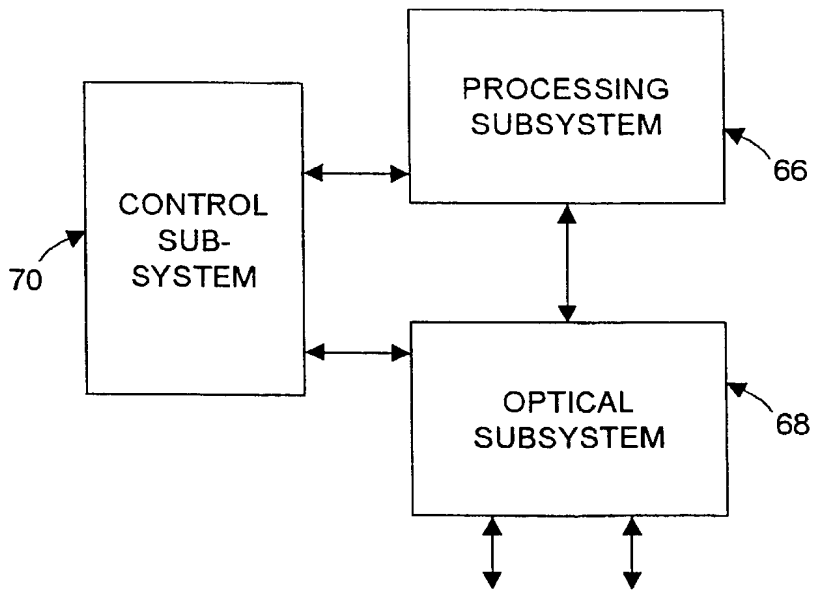


FIG. 3

3/12

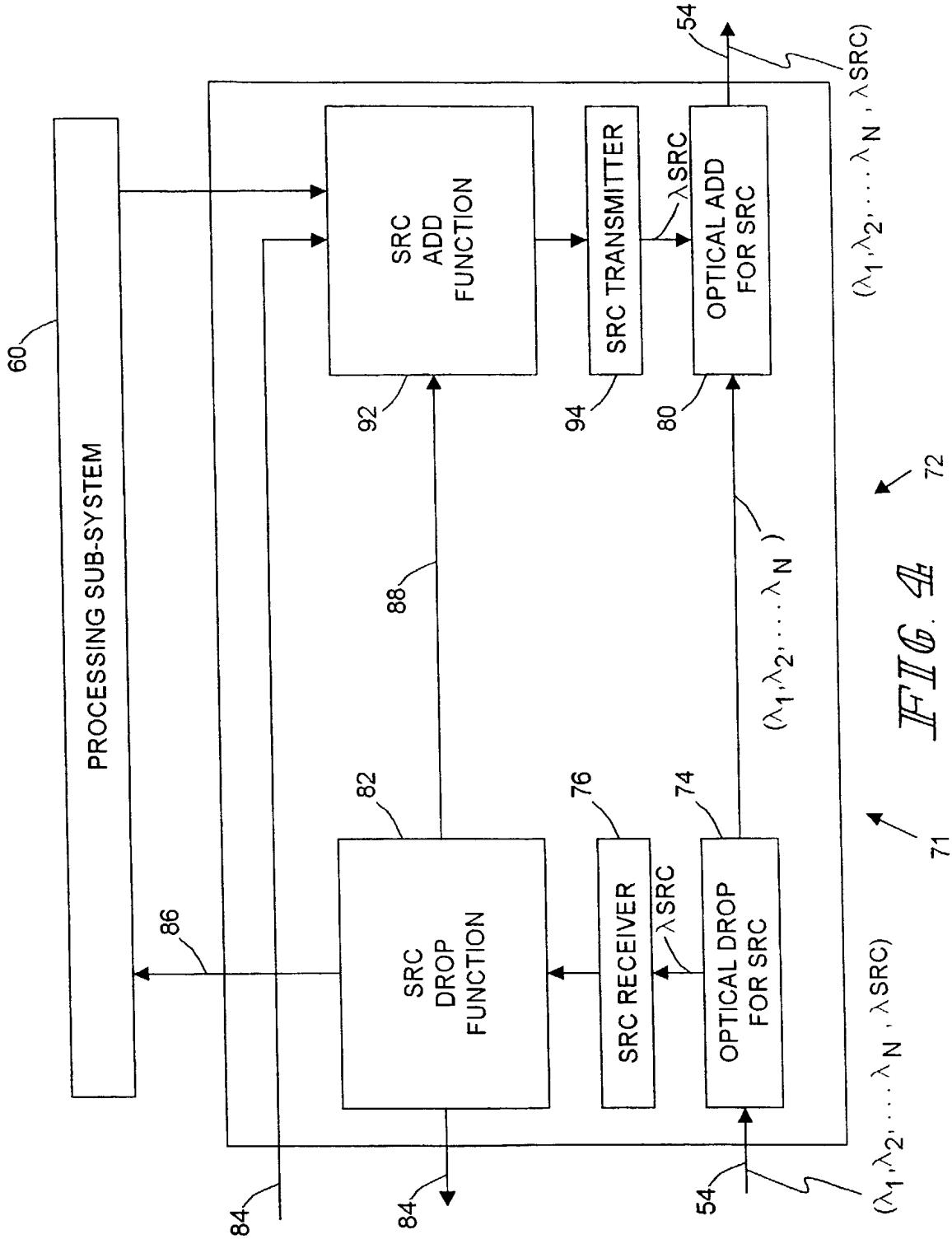


FIG. 4E



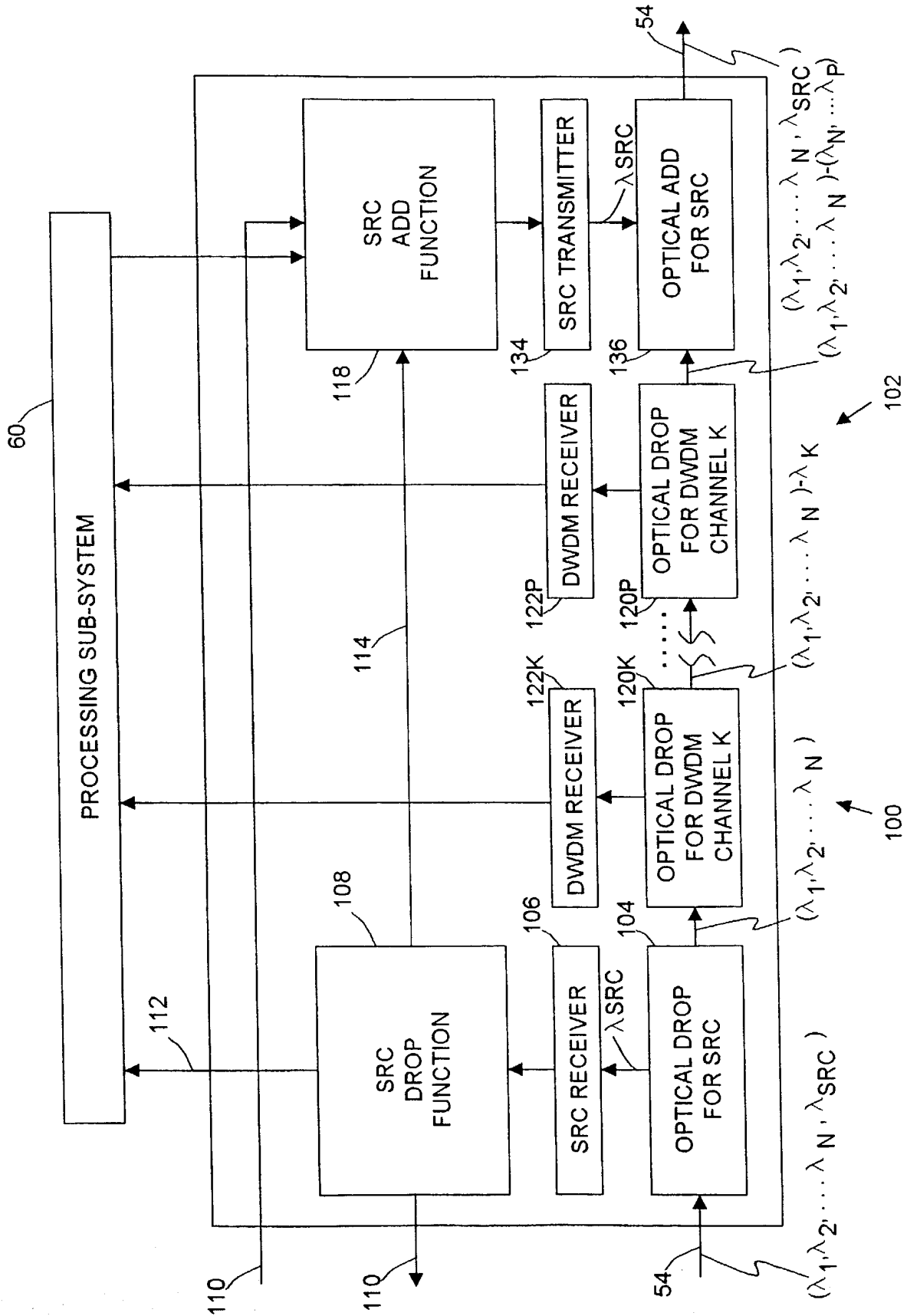
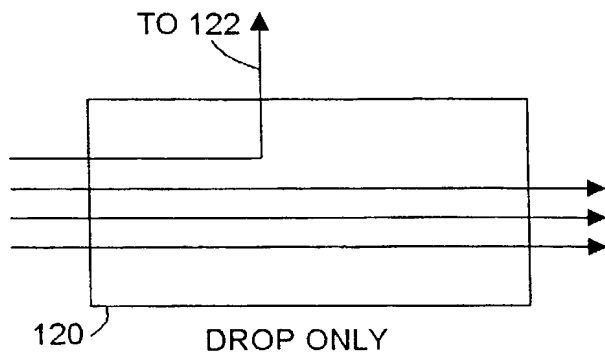
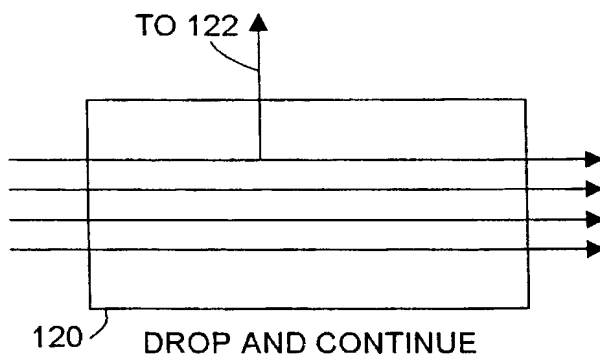


FIG. 5

5/12



*FIG. 6*



*FIG. 7*

6/12

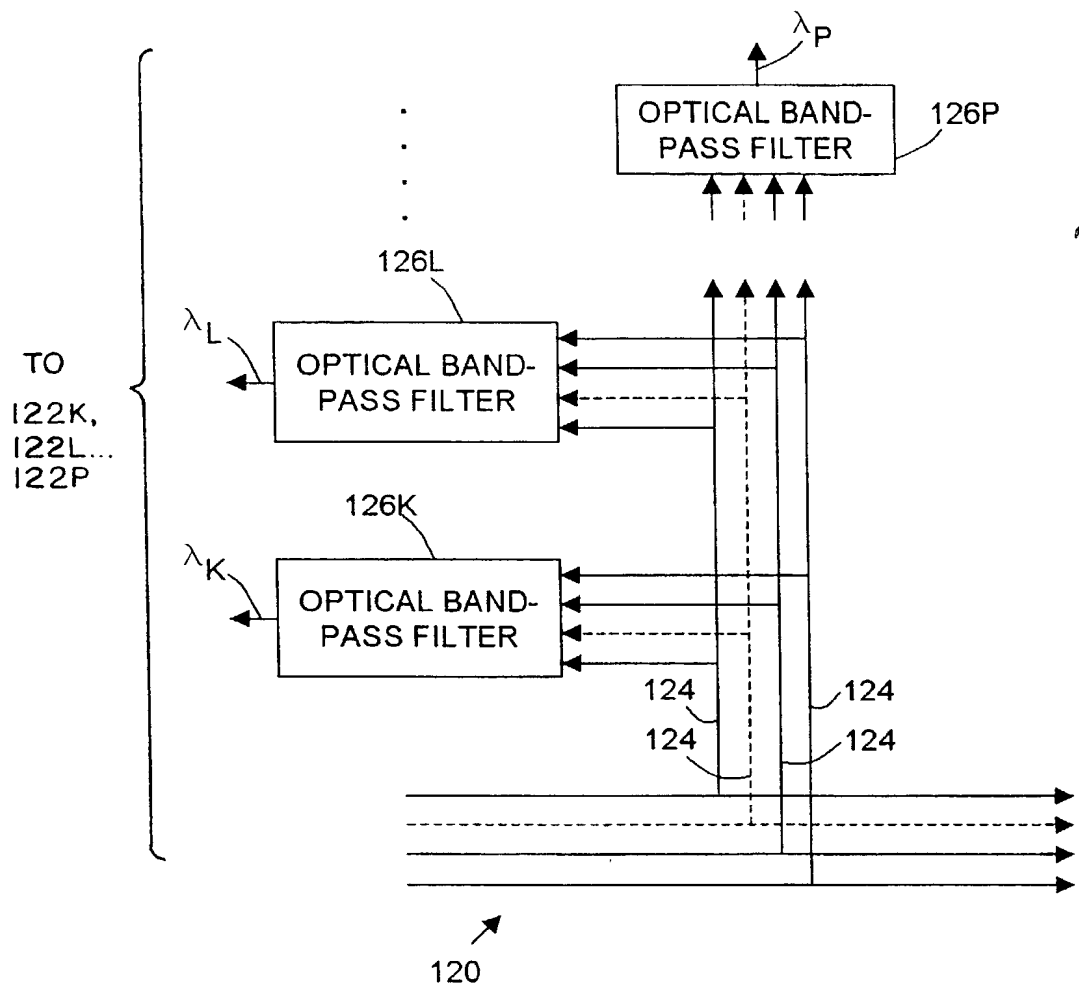


FIG. 8

7/12

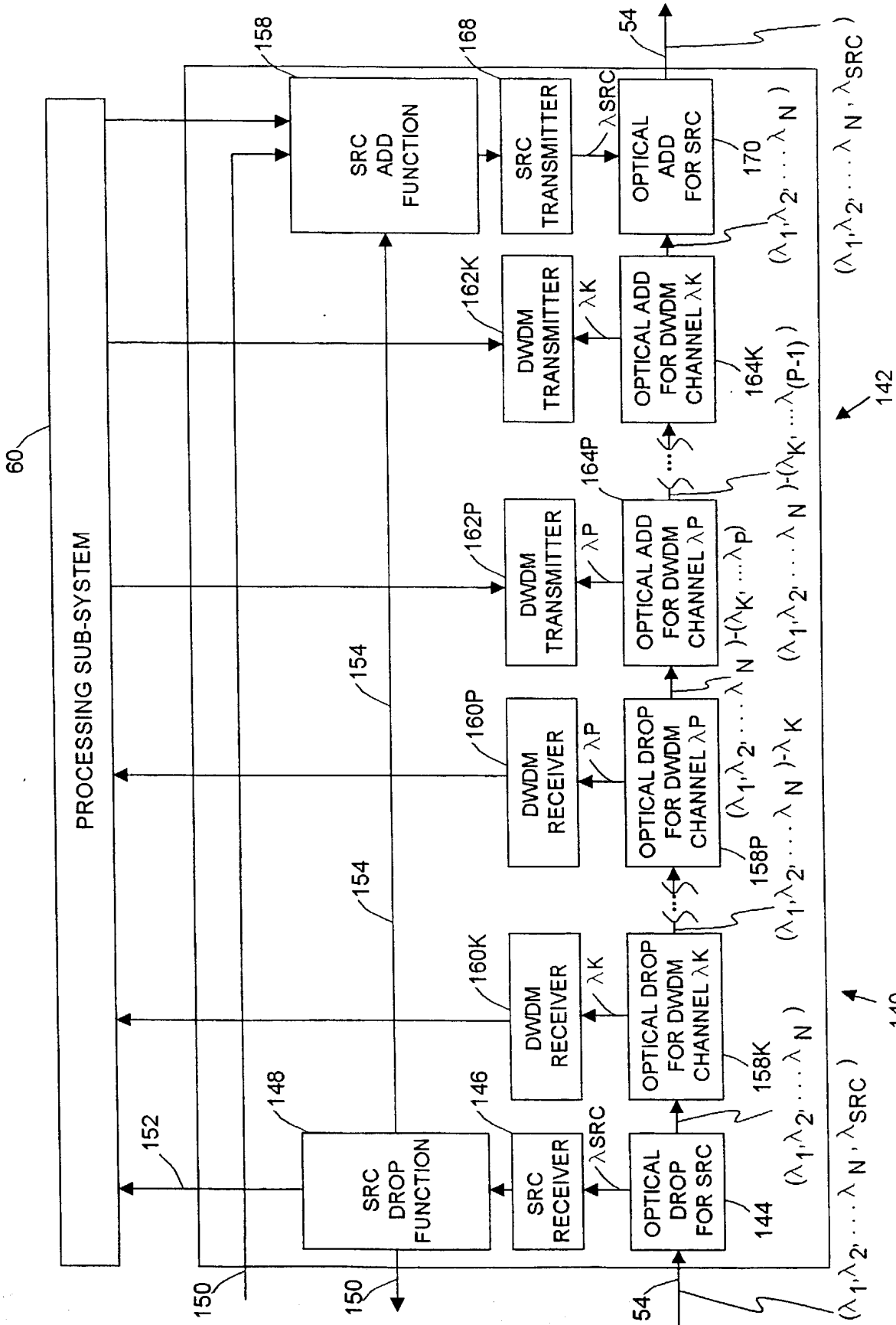
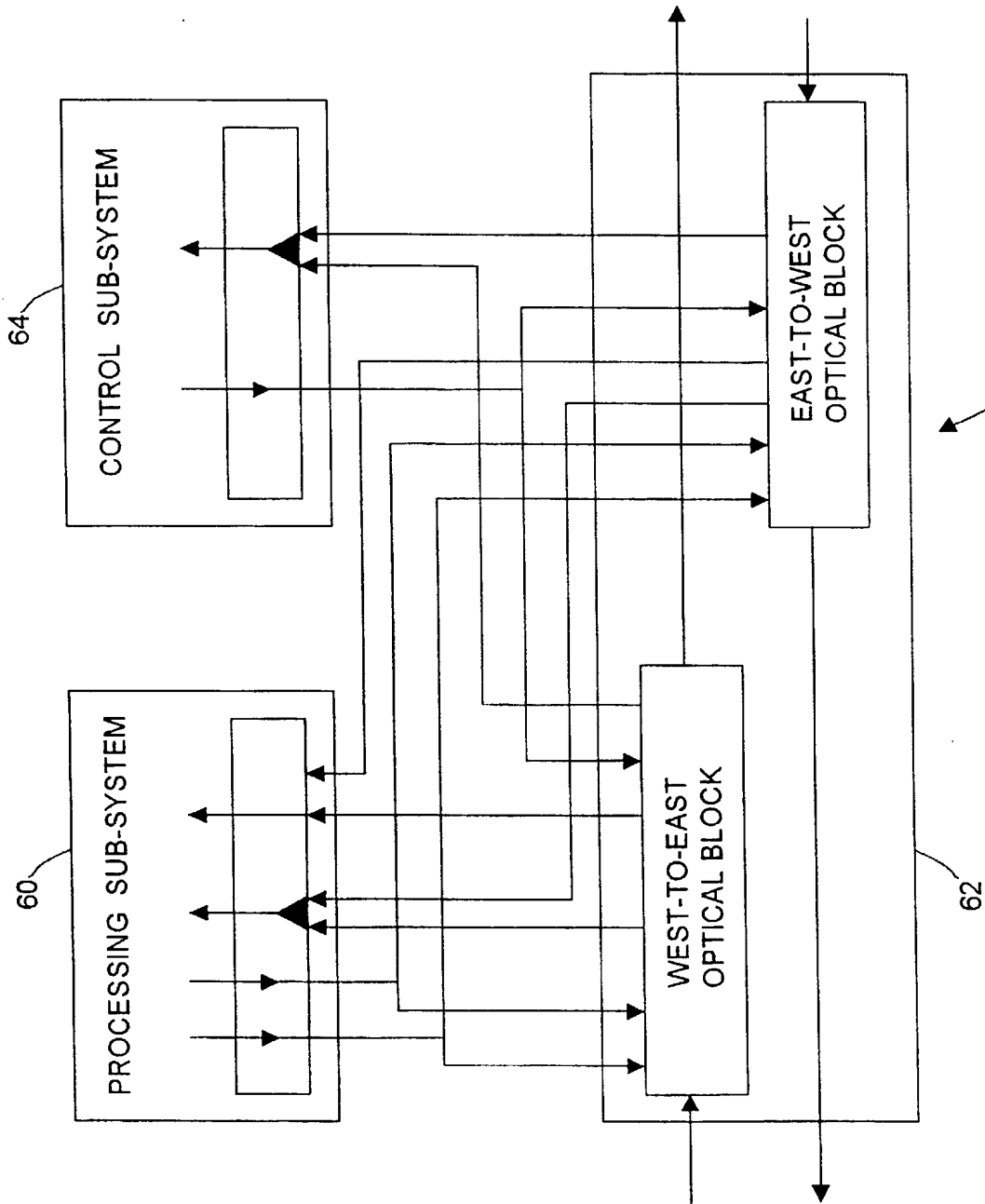


FIG. 9



52-2

FIG. 10

9/12

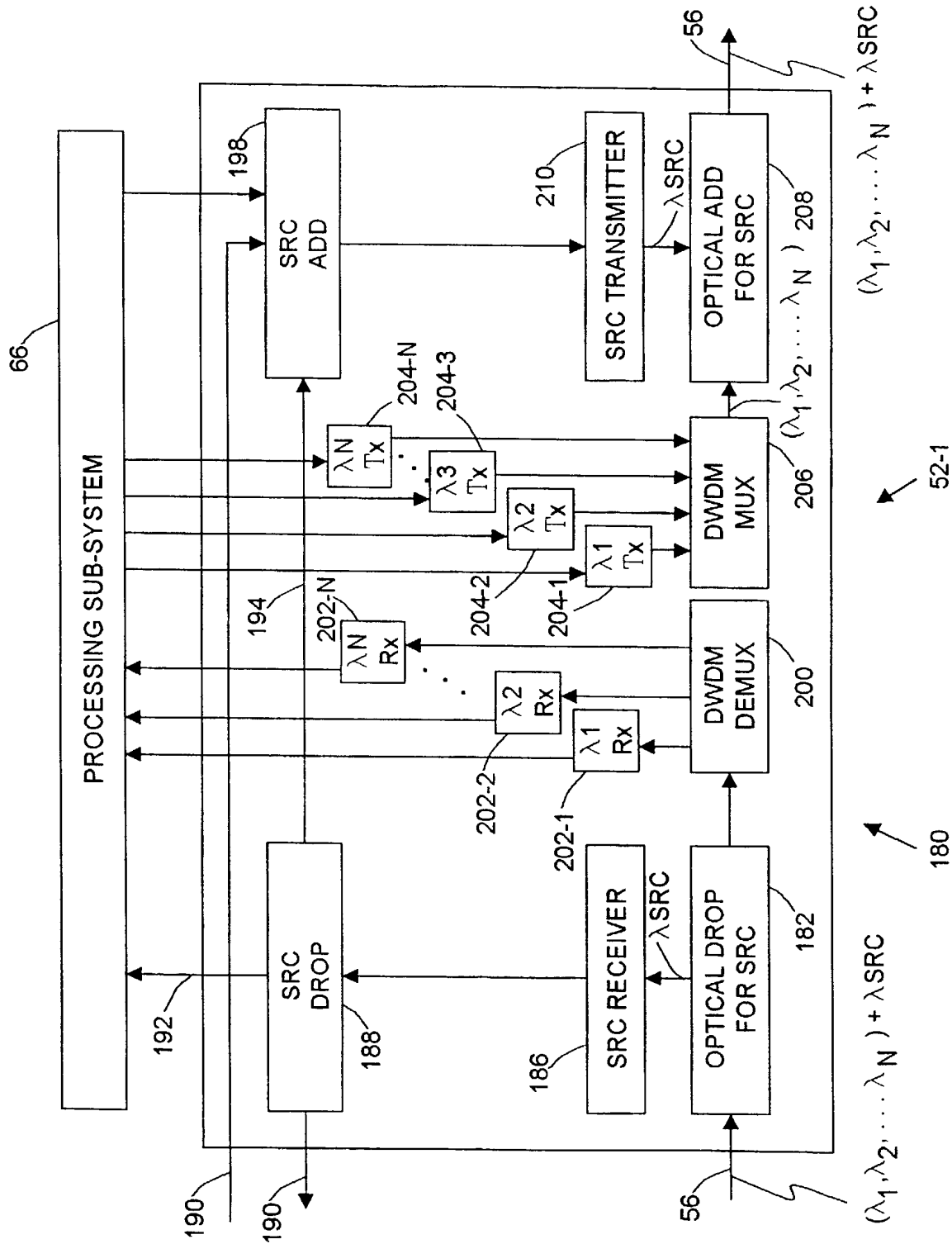
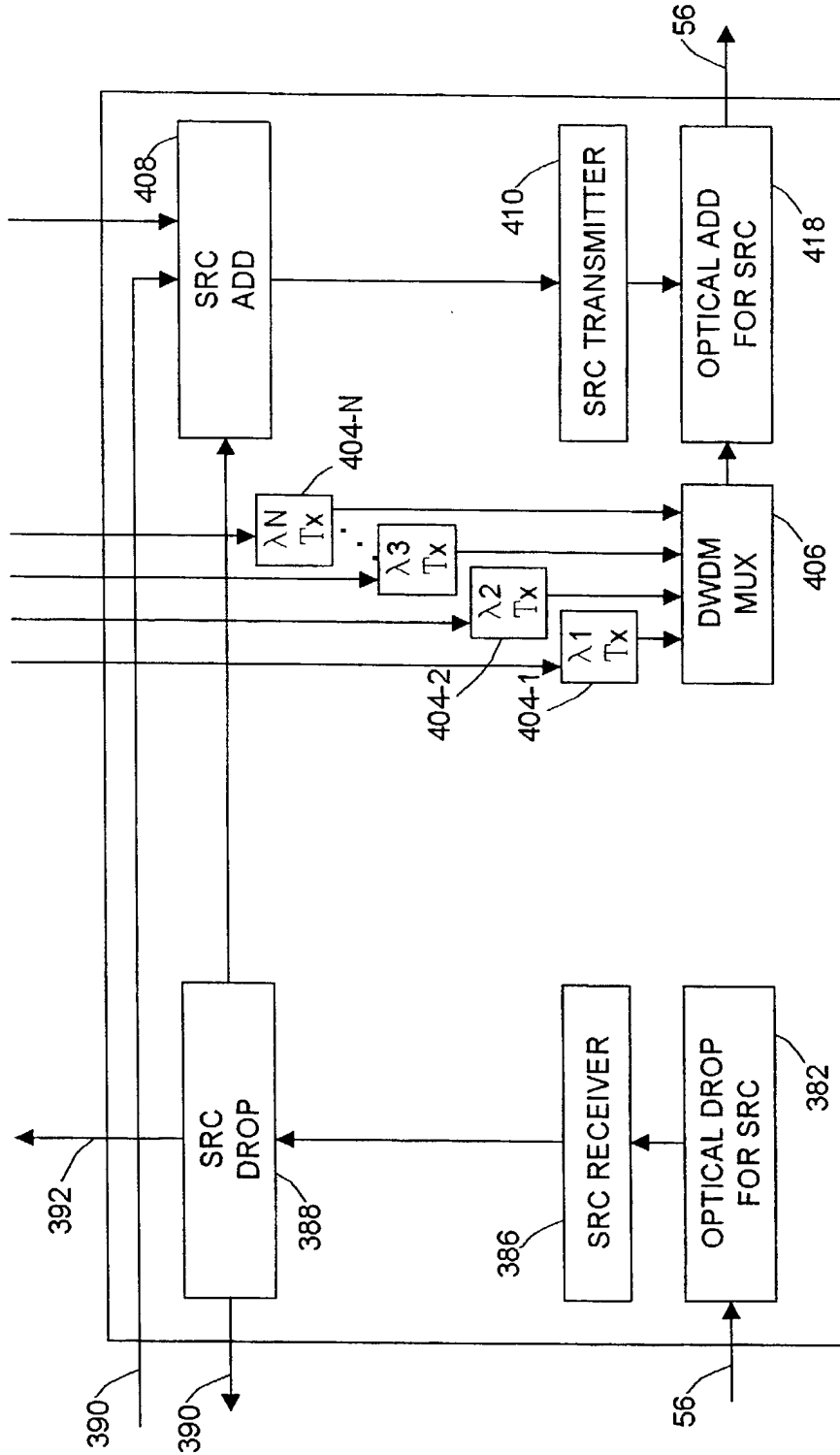


FIG. 11

10/12



52-1  
380  
*FIG. 12*

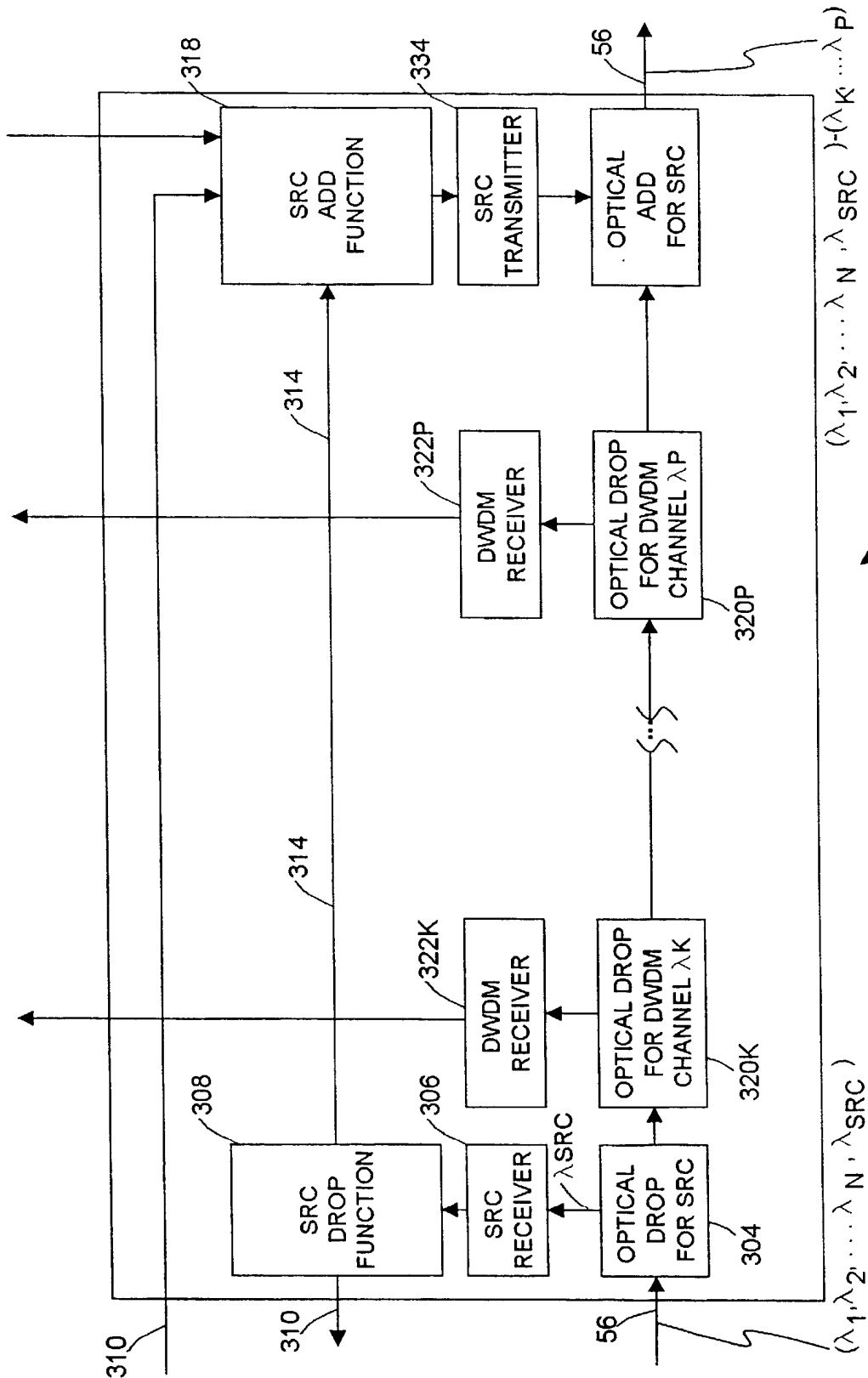


FIG. 13

52-2



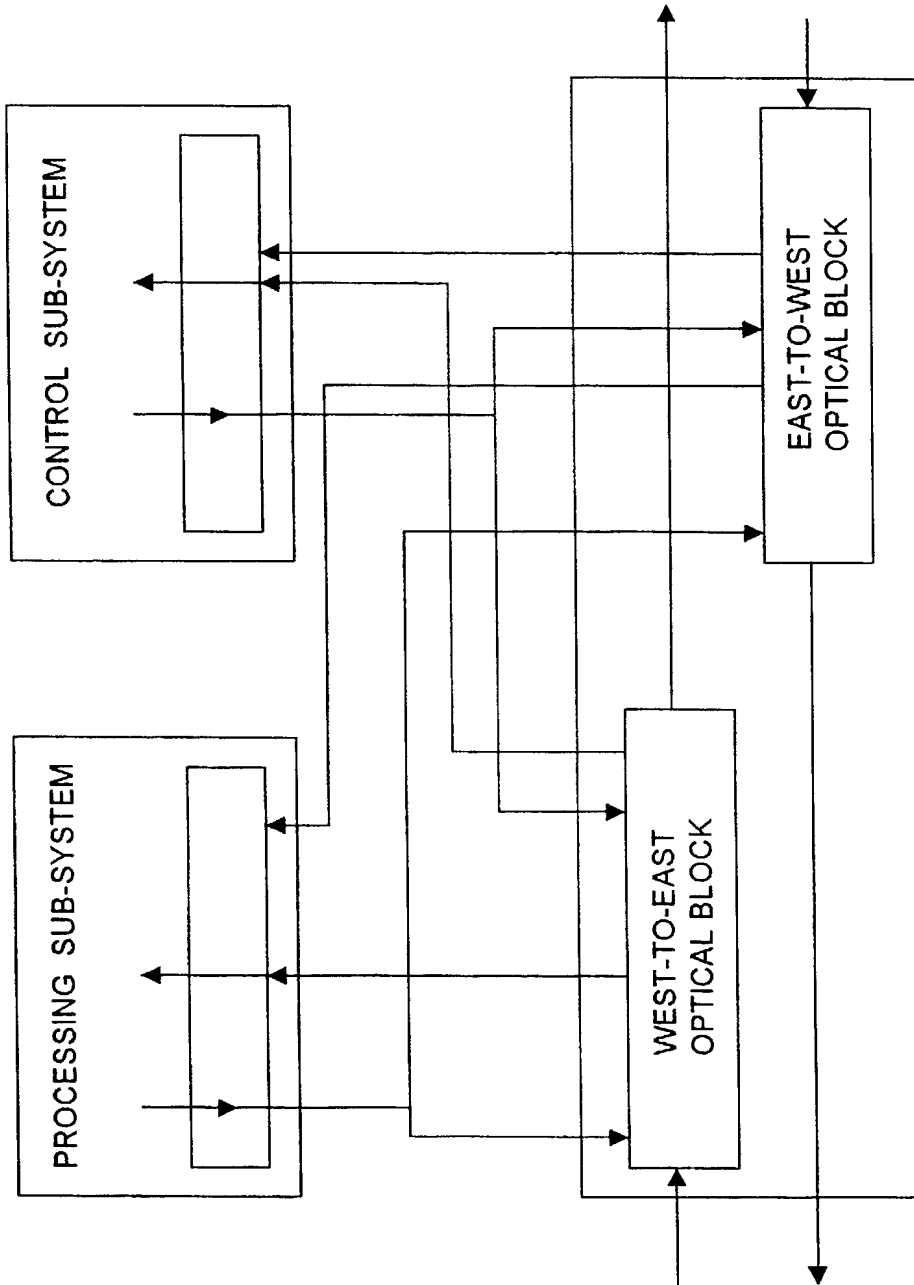


FIG. 14

Case Name and No.  
20568-68741

IN THE UNITED STATES  
PATENT AND TRADEMARK OFFICE

Declaration and Power of Attorney

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I hereby claim the benefit under Title 35, United States Code, 119(e) of any United States provisional application(s) identified below:

Provisional Application No. 60/120,222 filed on February 15, 1999

Provisional Application No. 60/122,882 filed on March 5, 1999

I believe I am an original, first and joint inventor of the subject matter which is claimed and for which a patent is sought on the invention entitled **FLEXIBLE AND SCALABLE ARCHITECTURE FOR DWDM NETWORKS IN FIBER RINGS** the specification of which was filed on 31 January 2000 as PCT International Application No. PCT/US00/02470.

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by an amendment, if any, specifically referred to in this oath or declaration.

I acknowledge the duty to disclose all information known to me which is material to patentability as defined in Title 37, Code of Federal Regulations, 1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, 119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

None

I hereby claim the benefit under Title 35, United States Code, 120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, 112, I acknowledge the duty to disclose all information known to me to be material to patentability as defined in Title 37, Code of Federal Regulations, 1.56 which

04/01

became available between the filing date of the prior application and the national or PCT international filing date of this application:

None

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

I hereby appoint the following attorney(s) with full power of substitution and revocation, to prosecute said application, to make alterations and amendments therein, to receive the patent, and to transact all business in the Patent and Trademark Office connected therewith:

|                        |                          |
|------------------------|--------------------------|
| Thomas J. Bean         | (Reg. No. <u>44528</u> ) |
| Lester H. Birnbaum     | (Reg. No. <u>25830</u> ) |
| Richard J. Botos       | (Reg. No. <u>32016</u> ) |
| Jeffery J. Brosemer    | (Reg. No. <u>36096</u> ) |
| Kenneth M. Brown       | (Reg. No. <u>37590</u> ) |
| Donald P. Dinella      | (Reg. No. <u>39961</u> ) |
| Guy Eriksen            | (Reg. No. <u>41736</u> ) |
| Martin I. Finston      | (Reg. No. <u>31613</u> ) |
| William S. Francos     | (Reg. No. <u>38456</u> ) |
| Barry H. Freedman      | (Reg. No. <u>26166</u> ) |
| Julio A. Garceran      | (Reg. No. <u>37138</u> ) |
| Jimmy Goo              | (Reg. No. <u>36528</u> ) |
| Anthony Grillo         | (Reg. No. <u>36535</u> ) |
| Stephen M. Gurey       | (Reg. No. <u>27336</u> ) |
| John M. Harman         | (Reg. No. <u>38173</u> ) |
| Matthew J. Hodulik     | (Reg. No. <u>36164</u> ) |
| Michael B. Johannesen  | (Reg. No. <u>35557</u> ) |
| Mark A. Kurisko        | (Reg. No. <u>38944</u> ) |
| Irena Lager            | (Reg. No. <u>39260</u> ) |
| John B. MacIntyre      | (Reg. No. <u>41170</u> ) |
| Christopher N. Malvone | (Reg. No. <u>34866</u> ) |
| Scott W. McLellan      | (Reg. No. <u>30776</u> ) |
| Martin G. Meder        | (Reg. No. <u>34674</u> ) |
| John C. Moran          | (Reg. No. <u>30782</u> ) |
| Michael A. Morra       | (Reg. No. <u>28975</u> ) |
| Gregory J. Murgia      | (Reg. No. <u>41209</u> ) |

Case Name and No.  
20568-68741

|                       |                          |
|-----------------------|--------------------------|
| Claude R. Narcisse    | (Reg. No. <u>38979</u> ) |
| Joseph J. Opalach     | (Reg. No. <u>36229</u> ) |
| Neil R. Ormos         | (Reg. No. <u>35309</u> ) |
| Eugen E. Pacher       | (Reg. No. <u>29964</u> ) |
| Jack R. Penrod        | (Reg. No. <u>31864</u> ) |
| Gregory C. Ranieri    | (Reg. No. <u>29695</u> ) |
| Scott J. Rittman      | (Reg. No. <u>39010</u> ) |
| Ferdinand M. Romano   | (Reg. No. <u>32752</u> ) |
| Eugene J. Rosenthal   | (Reg. No. <u>36658</u> ) |
| Bruce S. Schneider    | (Reg. No. <u>27949</u> ) |
| Ronald D. Slusky      | (Reg. No. <u>26585</u> ) |
| David L. Smith        | (Reg. No. <u>30592</u> ) |
| Ozer M. N. Teitelbaum | (Reg. No. <u>36698</u> ) |
| John P. Veschi        | (Reg. No. <u>39058</u> ) |
| David Volejnick       | (Reg. No. <u>29355</u> ) |
| Charles L. Warren     | (Reg. No. <u>27407</u> ) |
| Jeffrey M. Weinick    | (Reg. No. <u>36304</u> ) |
| Eli Weiss             | (Reg. No. <u>17765</u> ) |

I hereby appoint the attorney(s) on ATTACHMENT A as associate attorney(s) in the aforementioned application, with full power solely to prosecute said application, to make alterations and amendments therein, to receive the patent, and to transact all business in the Patent and Trademark Office connected with the prosecution of said application. No other powers are granted to such associate attorney(s) and such associate attorney(s) are specifically denied any power of substitution or revocation.

Full name of first joint inventor: Yair Oren

Inventor's signature *Yair Oren* Date 9/12/01

Residence: ~~13 Dissenchik Street, Tel-Aviv 69353 Israel~~ my

Citizenship: IL 3843 FARLISON ST. NW WASHINGTON DC 20016 USA  
DC

04/01

200

Full name of second joint inventor: Rafi Gidron

Inventor's signature [Signature] Date sep 27, 01

Residence: 78A Gali Techelet, Hertzlia 46640 Israel

Citizenship: IL ILY

Case Name and No.  
20568-68741

**ATTACHMENT A**

Attorney Name(s): Richard D. Conard Reg. No.: 27321

Telephone calls should be made to Richard D. Conard at:

Phone No.: 317-231-7285

Fax No.: 317-231-7433

All written communications are to be addressed to:

Richard D. Conard  
Barnes & Thornburg  
11 South Meridian Street  
Indianapolis, Indiana 46204

04/01